PCT

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(71) Applicant: MINNESOTA MINING AND MANUFACTUR-ING COMPANY [US/US]; 3M Center, P.O. Box 33427, Saint Paul, MN 55133-3427 (US).

(72) Inventors: ALLEN, Richard, C.; P.O. Box 33427, Saint Paul, MN 55133-3427 (US). CARLSON, Lockwood, W.; P.O. Box 33427, Saint Paul, MN 55133-3427 (US). OUDERKIRK, Andrew, J.; P.O. Box 33427, Saint Paul, MN 55133-3427 (US). WEBER, Michael, F.; P.O. Box 33427, Saint Paul, MN 55133-3427 (US). KOTZ, Arthur, L.; P.O. Box 33427, Saint Paul, MN 55133-3427 (US). NEVITT, Timothy, J.; P.O. Box 33427, Saint Paul, MN 55133-3427 (US). STOVER, Carl, A.; P.O. Box 33427, Saint Paul, MN 55133-3427 (US). MAJUMDAR, Biswaroop; P.O. Box 33427, Saint Paul, MN 55133-3427 (US).
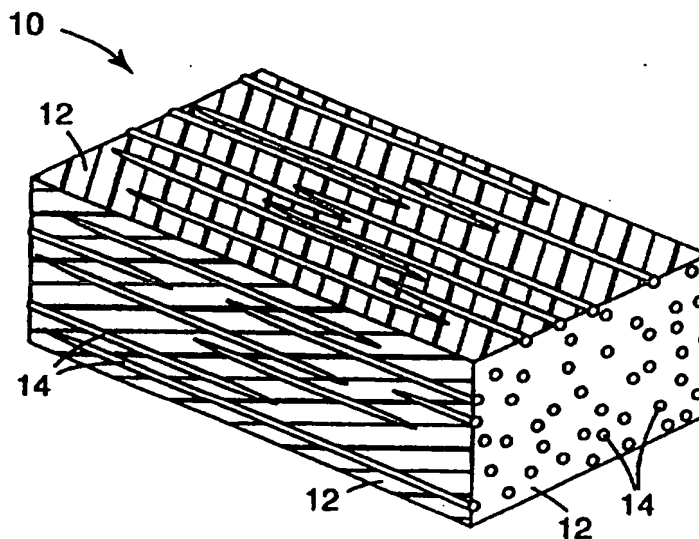
(74) Agents: FORTKORT, John, A. et al.; Minnesota Mining and Manufacturing Company, Office of Intellectual Property Counsel, P.O. Box 33427, Saint Paul, MN 55133-3427 (US).

(54) Title: BRIGHTNESS ENHANCEMENT FILM

(57) Abstract

An optical film is provided which comprises a disperse phase of polymeric particles disposed within a continuous birefringent matrix in combination with light directing materials to enable control of light emitted from a lighting fixture or display. The film is oriented, typically by stretching, in one or more directions. The size and shape of the disperse phase particles, the volume fraction of the disperse phase, the film thickness, and the amount of orientation are chosen to attain a desired degree of diffuse reflection and total transmission of electromagnetic radiation of a desired wavelength in the resulting film, and the light directing materials are chosen to control the direction of polarized light reflected from or transmitted by the optical film.

BRIGHTNESS ENHANCEMENT FILM

Field of the Invention

This invention relates to optical materials which contain structures suitable

5   for controlling optical characteristics, such as reflectance and transmission. In a further aspect, it relates to control of specific polarizations of reflected or transmitted light.

Background

10   Optical films are known to the art which are constructed from inclusions dispersed within a continuous matrix. The characteristics of these inclusions can be manipulated to provide a range of reflective and transmissive properties to the film. These characteristics include inclusion size with respect to wavelength within the film, inclusion shape and alignment, inclusion volumetric fill factor and

15   the degree of refractive index mismatch with the continuous matrix along the film's three orthogonal axes.

Conventional absorbing (dichroic) polarizers have, as their inclusion phase, inorganic rod-like chains of light-absorbing iodine which are aligned within a polymer matrix. Such a film will tend to absorb light polarized with its electric

20   field vector aligned parallel to the rod-like iodine chains, and to transmit light polarized perpendicular to the rods. Because the iodine chains have two or more dimensions that are small compared to the wavelength of visible light, and because the number of chains per cubic wavelength of light is large, the optical properties of such a film are predominately specular, with very little diffuse transmission

25   through the film or diffuse reflection from the film surfaces. Like most other commercially available polarizers, these polarizing films are based on polarization-selective absorption.

Films filled with inorganic inclusions with different characteristics can provide other optical transmission and reflective properties. For example, coated

30   mica flakes with two or more dimensions that are large compared with visible wavelengths, have been incorporated into polymeric films and into paints to impart

a metallic glitter. These flakes can be manipulated to lie in the plane of the film, thereby imparting a strong directional dependence to the reflective appearance. Such an effect can be used to produce security screens that are highly reflective for certain viewing angles, and transmissive for other viewing angles. Large flakes

5   having a coloration (specularly selective reflection) that depends on alignment with respect to incident light, can be incorporated into a film to provide evidence of tampering. In this application, it is necessary that all the flakes in the film be similarly aligned with respect to each other.

However, optical films made from polymers filled with inorganic

10   inclusions suffer from a variety of infirmities. Typically, adhesion between the inorganic particles and the polymer matrix is poor. Consequently, the optical properties of the film decline when stress or strain is applied across the matrix, both because the bond between the matrix and the inclusions is compromised, and because the rigid inorganic inclusions may be fractured. Furthermore, alignment of

15   inorganic inclusions requires process steps and considerations that complicate manufacturing.

Other films, such as that disclosed in U.S. 4,688,900 (Doane et. al.), consists of a clear light-transmitting continuous polymer matrix, with droplets of light modulating liquid crystals dispersed within. Stretching of the material

20   reportedly results in a distortion of the liquid crystal droplet from a spherical to an ellipsoidal shape, with the long axis of the ellipsoid parallel to the direction of stretch. U.S. 5,301,041 (Konuma et al.) make a similar disclosure, but achieve the distortion of the liquid crystal droplet through the application of pressure. A. Aphonin, "Optical Properties of Stretched Polymer Dispersed Liquid Crystal

25   Films: Angle-Dependent Polarized Light Scattering, Liquid Crystals, Vol. 19, No. 4, 469-480 (1995), discusses the optical properties of stretched films consisting of liquid crystal droplets disposed within a polymer matrix. He reports that the elongation of the droplets into an ellipsoidal shape, with their long axes parallel to the stretch direction, imparts an oriented birefringence (refractive index difference

30   among the dimensional axes of the droplet) to the droplets, resulting in a relative refractive index mismatch between the dispersed and continuous phases along

certain film axes, and a relative index match along the other film axes. Such liquid crystal droplets are not small as compared to visible wavelengths in the film, and thus the optical properties of such films have a substantial diffuse component to their reflective and transmissive properties. Aphonin suggests the use of these

5   materials as a polarizing diffuser for backlit twisted nematic LCDs. However, optical films employing liquid crystals as the disperse phase are substantially limited in the degree of refractive index mismatch between the matrix phase and the dispersed phase. Furthermore, the birefringence of the liquid crystal component of such films is typically sensitive to temperature.

10   U. S. 5,268,225 (Isayev) discloses a composite laminate made from thermotropic liquid crystal polymer blends. The blend consists of two liquid crystal polymers which are immiscible with each other. The blends may be cast into a film consisting of a dispersed inclusion phase and a continuous phase. When the film is stretched, the dispersed phase forms a series of fibers whose axes are

15   aligned in the direction of stretch. While the film is described as having improved mechanical properties, no mention is made of the optical properties of the film. However, due to their liquid crystal nature, films of this type would suffer from the infirmities of other liquid crystal materials discussed above.

Still other films have been made to exhibit desirable optical properties

20   through the application of electric or magnetic fields. For example, U. S. 5,008,807 (Waters et al.) describes a liquid crystal device which consists of a layer of fibers permeated with liquid crystal material and disposed between two electrodes. A voltage across the electrodes produces an electric field which changes the birefringent properties of the liquid crystal material, resulting in

25   various degrees of mismatch between the refractive indices of the fibers and the liquid crystal. However, the requirement of an electric or magnetic field is inconvenient and undesirable in many applications, particularly those where existing fields might produce interference.

Other optical films have been made by incorporating a dispersion of

30   inclusions of a first polymer into a second polymer, and then stretching the resulting composite in one or two directions. U. S. 4,871,784 (Otonari et al.) is

exemplative of this technology. The polymers are selected such that there is low adhesion between the dispersed phase and the surrounding matrix polymer, so that an elliptical void is formed around each inclusion when the film is stretched. Such voids have dimensions of the order of visible wavelengths. The refractive index

5   mismatch between the void and the polymer in these "microvoided" films is typically quite large (about 0.5), causing substantial diffuse reflection. However, the optical properties of microvoided materials are difficult to control because of variations of the geometry of the interfaces, and it is not possible to produce a film axis for which refractive indices are relatively matched, as would be useful for

10 polarization-sensitive optical properties. Furthermore, the voids in such material can be easily collapsed through exposure to heat and pressure.

Optical films have also been made wherein a dispersed phase is deterministically arranged in an ordered pattern within a continuous matrix. U. S. 5,217,794 (Schrenk) is exemplative of this technology. There, a lamellar

15 polymeric film is disclosed which is made of polymeric inclusions which are large compared with wavelength on two axes, disposed within a continuous matrix of another polymeric material. The refractive index of the dispersed phase differs significantly from that of the continuous phase along one or more of the laminate's axes, and is relatively well matched along another. Because of the ordering of the

20 dispersed phase, films of this type exhibit strong iridescence (i.e., interference-based angle dependent coloring) for instances in which they are substantially reflective. As a result, such films have seen limited use for optical applications where optical diffusion is desirable.

There thus remains a need in the art for an optical material consisting of a

25 continuous and a dispersed phase, wherein the refractive index mismatch between the two phases along the material's three dimensional axes can be conveniently and permanently manipulated to achieve desirable degrees of diffuse and specular reflection and transmission, wherein the optical material is stable with respect to stress, strain, temperature differences, and electric and magnetic fields, and

30 wherein the optical material has an insignificant level of iridescence. These and other needs are met by the present invention, as hereinafter disclosed.

Brief Description of the Drawings

FIG. 1 is a schematic drawing illustrating an optical body made in accordance with the present invention, wherein the disperse phase is arranged as a series of elongated masses having an essentially circular cross-section;

FIG. 2 is a schematic drawing illustrating an optical body made in accordance with the present invention, wherein the disperse phase is arranged as a series of elongated masses having an essentially elliptical cross-section;

FIGS. 3a-e are schematic drawings illustrating various shapes of the disperse phase in an optical body made in accordance with the present invention;

FIG. 4a is a graph of the bidirectional scatter distribution as a function of scattered angle for an oriented film in accordance with the present invention for light polarized perpendicular to orientation direction;

FIG. 4b is a graph of the bidirectional scatter distribution as a function of scattered angle for an oriented film in accordance with the present invention for light polarized parallel to orientation direction;

FIG. 5 is a schematic representation of a multilayer film made in accordance with the present invention;

FIGS. 6a and 6b are electron micrographs of optical films made in accordance with the present invention;

FIG. 7 is a perpendicular transmission spectrum for films made in accordance with the present invention;

FIG. 8 is a schematic diagram illustrating the use of the films of the present invention as high efficiency light extractors for optical fibers;

FIGS. 9A and 9B are graphs showing relative gain as a function of angle for the films of the present invention and for a commercially available optical film, respectively;

Figure 10 shows a side view of one preferred light directing material;

Figure 11 shows a graph illustrating the performance of the preferred light directing material shown in Figure 10;

Figure 12A and 12B show the reflectance and the transmittance properties, respectively, of a a first preferred embodiment of the direction control polarizer;

Figure 13A and 13B show the reflectance and the transmittance properties, respectively, of a second preferred embodiment of the direction control polarizer;

5   Figure 14 shows a schematic side view of a display incorporating the diffusely reflecting specularly transmitting polarizer;

Figure 15 shows a schematic side view of a display incorporating the first preferred embodiment of the direction control polarizer;

Figure 16 shows a side view of a display incorporating the second preferred

10   embodiment of the direction control polarizer;

Figure 17 shows a side view of a display incorporating the first preferred embodiment of the direction control polarizer and a second layer of light directing material; and

Figure 18 shows a graph of test results comparing the gain achieved in the

15   display configurations shown in Figures 11-14.

Summary of the Invention

In one aspect, the present invention relates to a diffusely reflective film or other optical body comprising a birefringent continuous polymeric phase and a

20   substantially nonbirefringent disperse phase disposed within the continuous phase. The indices of refraction of the continuous and disperse phases are substantially mismatched (i.e., differ from one another by more than about 0.05) along a first of three mutually orthogonal axes, and are substantially matched (i.e., differ by less than about 0.05) along a second of three mutually orthogonal axes. In some

25   embodiments, the indices of refraction of the continuous and disperse phases can be substantially matched or mismatched along, or parallel to, a third of three mutually orthogonal axes to produce a mirror or a polarizer. Incident light polarized along, or parallel to, a mismatched axis is scattered, resulting in significant diffuse reflection. Incident light polarized along a matched axis is

30   scattered to a much lesser degree and is significantly spectrally transmitted. These properties can be used to make optical films for a variety of uses, including low

loss (significantly nonabsorbing) reflective polarizers for which polarizations of light that are not significantly transmitted are diffusely reflected.

In a related aspect, the present invention relates to an optical film or other optical body comprising a birefringent continuous phase and a disperse phase,

5   wherein the indices of refraction of the continuous and disperse phases are substantially matched (i.e., wherein the index difference between the continuous and disperse phases is less than about 0.05) along an axis perpendicular to a surface of the optical body.

In another aspect, the present invention relates to a composite optical body

10   comprising a polymeric continuous birefringent first phase in which the disperse second phase may be birefringent, but in which the degree of match and mismatch in at least two orthogonal directions is primarily due to the birefringence of the first phase.

In still another aspect, the present invention relates to a method for

15   obtaining a diffuse reflective polarizer, comprising the steps of: providing a first resin, whose degree of birefringence can be altered by application of a force field, as through dimensional orientation or an applied electric field, such that the resulting resin material has, for at least two orthogonal directions, an index of refraction difference of more than about 0.05; providing a second resin, dispersed

20   within the first resin; and applying said force field to the composite of both resins such that the indices of the two resins are approximately matched to within less than about 0.05 in one of two directions, and the index difference between first and second resins in the other of two directions is greater than about 0.05. In a related embodiment, the second resin is dispersed in the first resin after imposition of the

25   force field and subsequent alteration of the birefringence of the first resin.

In yet another aspect, the present invention relates to an optical body acting as a reflective polarizer with a high extinction ratio. In this aspect, the index difference in the match direction is chosen as small as possible and the difference in the mismatch direction is maximized. The volume fraction, thickness, and

30   disperse phase particle size and shape can be chosen to maximize the extinction

ratio, although the relative importance of optical transmission and reflection for the different polarizations may vary for different applications.

In another aspect, the present invention relates to an optical body comprising a continuous phase, a disperse phase whose index of refraction differs
5   from said continuous phase by greater than about 0.05 along a first axis and by less than about 0.05 along a second axis orthogonal to said first axis, and a dichroic dye. The optical body is preferably oriented along at least one axis. The dichroic dye improves the extinction coefficient of the optical body by absorbing, in addition to scattering, light polarized parallel to the axis of orientation.

10 In another aspect of the present invention, an optical body is provided which has at least first and second phases that are co-continuous along at least one axis. The index of refraction of the first phase differs from that of the second phase by greater than about 0.05 along a first axis and by less than about 0.05 along a second axis orthogonal to said first axis. In other embodiments, three or more co-
15 continuous phases may be used to achieve the same or similar matches and mismatches along mutually perpendicular axes.

In still another aspect of the present invention, an optical body is provided which comprises a film having a continuous and disperse phase, with an antireflective layer disposed thereon. Such films exhibit a flat transmission curve
20 as a function of the wavelength of light, which tends to minimize any changes in color to a resultant display device into which the reflective polarizer is incorporated.

In the various aspects of the present invention, the reflection and transmission properties for at least two orthogonal polarizations of incident light
25 are determined by the selection or manipulation of various parameters, including the optical indices of the continuous and disperse phases, the size and shape of the disperse phase particles, the volume fraction of the disperse phase, the thickness of the optical body through which some fraction of the incident light is to pass, and the wavelength or wavelength band of electromagnetic radiation of interest.

30 The magnitude of the index match or mismatch along a particular axis will directly affect the degree of scattering of light polarized along that axis. In general,

scattering power varies as the square of the index mismatch. Thus, the larger the index mismatch along a particular axis, the stronger the scattering of light polarized along that axis. Conversely, when the mismatch along a particular axis is small, light polarized along that axis is scattered to a lesser extent and is thereby

5   transmitted specularly through the volume of the body.

The size of the disperse phase also can have a significant effect on scattering. If the disperse phase particles are too small (i.e., less than about 1/30 the wavelength of light in the medium of interest) and if there are many particles per cubic wavelength, the optical body behaves as a medium with an effective

10   index of refraction somewhat between the indices of the two phases along any given axis. In such a case, very little light is scattered. If the particles are too large, the light is specularly reflected from the particle surface, with very little diffusion into other directions. When the particles are too large in at least two orthogonal directions, undesirable iridescence effects can also occur. Practical

15   limits may also be reached when particles become large in that the thickness of the optical body becomes greater and desirable mechanical properties are compromised.

The shape of the particles of the disperse phase can also have an effect on the scattering of light. The depolarization factors of the particles for the electric

20   field in the index of refraction match and mismatch directions can reduce or enhance the amount of scattering in a given direction. The effect can either add or detract from the amount of scattering from the index mismatch, but generally has a small influence on scattering in the preferred range of properties in the present invention.

25   The shape of the particles can also influence the degree of diffusion of light scattered from the particles. This shape effect is generally small but increases as the aspect ratio of the geometrical cross-section of the particle in the plane perpendicular to the direction of incidence of the light increases and as the particles get relatively larger. In general, in the operation of this invention, the disperse

30   phase particles should be sized less than several wavelengths of light in one or two

mutually orthogonal dimensions if diffuse, rather than specular, reflection is preferred.

Dimensional alignment is also found to have an effect on the scattering behavior of the disperse phase. In particular, it has been observed, in optical

5   bodies made in accordance with the present invention, that aligned scatterers will not scatter light symmetrically about the directions of specular transmission or reflection as randomly aligned scatterers would. In particular, inclusions that have been elongated by orientation to resemble rods scatter light primarily along (or near) a cone centered on the orientation direction and having an edge along the

10 specularly transmitted direction. For example, for light incident on such an elongated rod in a direction perpendicular to the orientation direction, the scattered light appears as a band of light in the plane perpendicular to the orientation direction with an intensity that decreases with increasing angle away from the specular directions. By tailoring the geometry of the inclusions, some control over

15 the distribution of scattered light can be achieved both in the transmissive hemisphere and in the reflective hemisphere.

The volume fraction of the disperse phase also affects the scattering of light in the optical bodies of the present invention. Within certain limits, increasing the volume fraction of the disperse phase tends to increase the amount of scattering

20 that a light ray experiences after entering the body for both the match and mismatch directions of polarized light. This factor is important for controlling the reflection and transmission properties for a given application. However, if the volume fraction of the disperse phase becomes too large, light scattering diminishes. Without wishing to be bound by theory, this appears to be due to the

25 fact that the disperse phase particles are closer together, in terms of the wavelength of light, so that the particles tend to act together as a smaller number of large effective particles.

The thickness of the optical body is also an important control parameter which can be manipulated to affect reflection and transmission properties in the

30 present invention. As the thickness of the optical body increases, diffuse reflection also increases, and transmission, both specular and diffuse, decreases.

While the present invention will often be described herein with reference to the visible region of the spectrum, various embodiments of the present invention can be used to operate at different wavelengths (and thus frequencies) of electromagnetic radiation through appropriate scaling of the components of the optical body. Thus, as the wavelength increases, the linear size of the components of the optical body are increased so that the dimensions, measured in units of wavelength, remain approximately constant. Another major effect of changing wavelength is that, for most materials of interest, the index of refraction and the absorption coefficient change. However, the principles of index match and mismatch still apply at each wavelength of interest.

Detailed Description of the Invention

Introduction

As used herein, the terms "specular reflection" and "specular reflectance" refer to the reflectance of light rays into an emergent cone with a vertex angle of 16 degrees centered around the specular angle. The terms "diffuse reflection" or "diffuse reflectance" refer to the reflection of rays that are outside the specular cone defined above. The terms "total reflectance" or "total reflection" refer to the combined reflectance of all light from a surface. Thus, total reflection is the sum of specular and diffuse reflection.

Similarly, the terms "specular transmission" and "specular transmittance" are used herein in reference to the transmission of rays into an emergent cone with a vertex angle of 16 degrees centered around the specular direction. The terms "diffuse transmission" and "diffuse transmittance" are used herein in reference to the transmission of all rays that are outside the specular cone defined above. The terms "total transmission" or "total transmittance" refer to the combined transmission of all light through an optical body. Thus, total transmission is the sum of specular and diffuse transmission.

As used herein, the term "extinction ratio" is defined to mean the ratio of total light transmitted in one polarization to the light transmitted in an orthogonal polarization.

FIGS. 1-2 illustrate a first embodiment of the present invention. In accordance with the invention, a diffusely reflective optical film 10 or other optical body is produced which consists of a birefringent matrix or continuous phase 12 and a discontinuous or disperse phase 14. The birefringence of the continuous phase is typically at least about 0.05, preferably at least about 0.1, more preferably at least about 0.15, and most preferably at least about 0.2.

The indices of refraction of the continuous and disperse phases are substantially matched (i.e., differ by less than about 0.05) along a first of three mutually orthogonal axes, and are substantially mismatched (i.e., differ by more than about 0.05) along a second of three mutually orthogonal axes. Preferably, the indices of refraction of the continuous and disperse phases differ by less than about 0.03 in the match direction, more preferably, less than about 0.02, and most preferably, less than about 0.01. The indices of refraction of the continuous and disperse phases preferably differ in the mismatch direction by at least about 0.07, more preferably, by at least about 0.1, and most preferably, by at least about 0.2.

The mismatch in refractive indices along a particular axis has the effect that incident light polarized along that axis will be substantially scattered, resulting in a significant amount of reflection. By contrast, incident light polarized along an axis in which the refractive indices are matched will be spectrally transmitted or reflected with a much lesser degree of scattering. This effect can be utilized to make a variety of optical devices, including reflective polarizers and mirrors.

The present invention provides a practical and simple optical body and method for making a reflective polarizer, and also provides a means of obtaining a continuous range of optical properties according to the principles described herein. Also, very efficient low loss polarizers can be obtained with high extinction ratios. Other advantages are a wide range of practical materials for the disperse phase and the continuous phase, and a high degree of control in providing optical bodies of consistent and predictable high quality performance.

Effect of Index Match/Mismatch

In the preferred embodiment, the materials of at least one of the continuous and disperse phases are of a type that undergoes a change in refractive index upon orientation. Consequently, as the film is oriented in one or more directions,

5   refractive index matches or mismatches are produced along one or more axes. By careful manipulation of orientation parameters and other processing conditions, the positive or negative birefringence of the matrix can be used to induce diffuse reflection or transmission of one or both polarizations of light along a given axis. The relative ratio between transmission and diffuse reflection is dependent on the

10   concentration of the disperse phase inclusions, the thickness of the film, the square of the difference in the index of refraction between the continuous and disperse phases, the size and geometry of the disperse phase inclusions, and the wavelength or wavelength band of the incident radiation.

The magnitude of the index match or mismatch along a particular axis

15   directly affects the degree of scattering of light polarized along that axis. In general, scattering power varies as the square of the index mismatch. Thus, the larger the index mismatch along a particular axis, the stronger the scattering of light polarized along that axis. Conversely, when the mismatch along a particular axis is small, light polarized along that axis is scattered to a lesser extent and is

20   thereby transmitted specularly through the volume of the body.

FIGS. 4a-b demonstrate this effect in oriented films made in accordance with the present invention. There, a typical Bidirectional Scatter Distribution Function (BSDF) measurement is shown for normally incident light at 632.8 nm. The BSDF is described in J. Stover, "Optical Scattering Measurement and

25   Analysis" (1990). The BSDF is shown as a function of scattered angle for polarizations of light both perpendicular and parallel to the axis of orientation. A scattered angle of zero corresponds to unscattered (spectrally transmitted) light. For light polarized in the index match direction (that is, perpendicular to the orientation direction) as in FIG. 4a, there is a significant specularly transmitted

30   peak with a sizable component of diffusely transmitted light (scattering angle between 8 and 80 degrees), and a small component of diffusely reflected light

(scattering angle larger than 100 degrees). For light polarized in the index mismatch direction (that is, parallel to the orientation direction) as in FIG. 4b, there is negligible specularly transmitted light and a greatly reduced component of diffusely transmitted light, and a sizable diffusely reflected component. It should

5   be noted that the plane of scattering shown by these graphs is the plane perpendicular to the orientation direction where most of the scattered light exists for these elongated inclusions. Scattered light contributions outside of this plane are greatly reduced.

       If the index of refraction of the inclusions (i.e., the disperse phase) matches

10   that of the continuous host media along some axis, then incident light polarized with electric fields parallel to this axis will pass through unscattered regardless of the size, shape, and density of inclusions. If the indices are not matched along some axis, then the inclusions will scatter light polarized along this axis. For scatterers of a given cross-sectional area with dimensions larger than

15   approximately $\lambda/30$ (where λ is the wavelength of light in the media), the strength of the scattering is largely determined by the index mismatch. The exact size, shape and alignment of a mismatched inclusion play a role in determining how much light will be scattered into various directions from that inclusion. If the density and thickness of the scattering layer is sufficient, according to multiple

20   scattering theory, incident light will be either reflected or absorbed, but not transmitted, regardless of the details of the scatterer size and shape.

       When the material is to be used as a polarizer, it is preferably processed, as by stretching and allowing some dimensional relaxation in the cross stretch in-plane direction, so that the index of refraction difference between the continuous

25   and disperse phases is large along a first axis in a plane parallel to a surface of the material and small along the other two orthogonal axes. This results in a large optical anisotropy for electromagnetic radiation of different polarizations.

       Some of the polarizers within the scope of the present invention are elliptical polarizers. In general, elliptical polarizers will have a difference in index

30   of refraction between the disperse phase and the continuous phase for both the stretch and cross-stretch directions. The ratio of forward to back scattering is

dependent on the difference in refractive index between the disperse and continuous phases, the concentration of the disperse phase, the size and shape of the disperse phase, and the overall thickness of the film. In general, elliptical diffusers have a relatively small difference in index of refraction between the

5   particles of the disperse and continuous phases. By using a birefringent polymer-based diffuser, highly elliptical polarization sensitivity (i.e., diffuse reflectivity depending on the polarization of light) can be achieved. At an extreme, where the index of refraction of the polymers match on one axis, the elliptical polarizer will be a diffuse reflecting polarizer.

10

Methods of Obtaining Index Match/Mismatch

The materials selected for use in a polarizer in accordance with the present invention, and the degree of orientation of these materials, are preferably chosen so that the phases in the finished polarizer have at least one axis for which the

15   associated indices of refraction are substantially equal. The match of refractive indices associated with that axis, which typically, but not necessarily, is an axis transverse to the direction of orientation, results in substantially no reflection of light in that plane of polarization.

The disperse phase may also exhibit a decrease in the refractive index

20   associated with the direction of orientation after stretching. If the birefringence of the host is positive, a negative strain induced birefringence of the disperse phase has the advantage of increasing the difference between indices of refraction of the adjoining phases associated with the orientation axis while the reflection of light with its plane of polarization perpendicular to the orientation direction is still

25   negligible. Differences between the indices of refraction of adjoining phases in the direction orthogonal to the orientation direction should be less than about 0.05 after orientation, and preferably, less than about 0.02.

The disperse phase may also exhibit a positive strain induced birefringence. However, this can be altered by means of heat treatment to match the refractive

30   index of the axis perpendicular to the orientation direction of the continuous phase.

The temperature of the heat treatment should not be so high as to relax the birefringence in the continuous phase.

Size of Disperse Phase

5   The size of the disperse phase also can have a significant effect on scattering. If the disperse phase particles are too small (i.e., less than about 1/30 the wavelength of light in the medium of interest) and if there are many particles per cubic wavelength, the optical body behaves as a medium with an effective index of refraction somewhat between the indices of the two phases along any

10   given axis. In such a case, very little light is scattered. If the particles are too large, the light is specularly reflected from the surface of the particle, with very little diffusion into other directions. When the particles are too large in at least two orthogonal directions, undesirable iridescence effects can also occur. Practical limits may also be reached when particles become large in that the thickness of the

15   optical body becomes greater and desirable mechanical properties are compromised.

The dimensions of the particles of the disperse phase after alignment can vary depending on the desired use of the optical material. Thus, for example, the dimensions of the particles may vary depending on the wavelength of

20   electromagnetic radiation that is of interest in a particular application, with different dimensions required for reflecting or transmitting visible, ultraviolet, infrared, and microwave radiation. Generally, however, the length of the particles should be such that they are approximately greater than the wavelength of electromagnetic radiation of interest in the medium, divided by 30.

25   Preferably, in applications where the optical body is to be used as a low loss reflective polarizer, the particles will have a length that is greater than about 2 times the wavelength of the electromagnetic radiation over the wavelength range of interest, and preferably over 4 times the wavelength. The average diameter of the particles is preferably equal or less than the wavelength of the electromagnetic

30   radiation over the wavelength range of interest, and preferably less than 0.5 of the desired wavelength. While the dimensions of the disperse phase are a secondary

consideration in most applications, they become of greater importance in thin film applications, where there is comparatively little diffuse reflection.

Geometry of Disperse Phase

5   While the index mismatch is the predominant factor relied upon to promote scattering in the films of the present invention (i.e., a diffuse mirror or polarizer made in accordance with the present invention has a substantial mismatch in the indices of refraction of the continuous and disperse phases along at least one axis), the geometry of the particles of the disperse phase can have a secondary effect on

10   scattering. Thus, the depolarization factors of the particles for the electric field in the index of refraction match and mismatch directions can reduce or enhance the amount of scattering in a given direction. For example, when the disperse phase is elliptical in a cross-section taken along a plane perpendicular to the axis of orientation, the elliptical cross-sectional shape of the disperse phase contributes to

15   the asymmetric diffusion in both back scattered light and forward scattered light. The effect can either add or detract from the amount of scattering from the index mismatch, but generally has a small influence on scattering in the preferred range of properties in the present invention.

The shape of the disperse phase particles can also influence the degree of

20   diffusion of light scattered from the particles. This shape effect is generally small but increases as the aspect ratio of the geometrical cross-section of the particle in the plane perpendicular to the direction of incidence of the light increases and as the particles get relatively larger. In general, in the operation of this invention, the disperse phase particles should be sized less than several wavelengths of light in

25   one or two mutually orthogonal dimensions if diffuse, rather than specular, reflection is preferred.

Preferably, for a low loss reflective polarizer, the preferred embodiment consists of a disperse phase disposed within the continuous phase as a series of rod-like structures which, as a consequence of orientation, have a high aspect ratio

30   which can enhance reflection for polarizations parallel to the orientation direction by increasing the scattering strength and dispersion for that polarization relative to

polarizations perpendicular to the orientation direction. However, as indicated in FIGS. 3a-e, the disperse phase may be provided with many different geometries. Thus, the disperse phase may be disk-shaped or elongated disk-shaped, as in FIGS. 3a-c, rod-shaped, as in FIG. 3d-e, or spherical. Other embodiments are

5   contemplated wherein the disperse phase has cross sections which are approximately elliptical (including circular), polygonal, irregular, or a combination of one or more of these shapes. The cross-sectional shape and size of the particles of the disperse phase may also vary from one particle to another, or from one region of the film to another (i.e., from the surface to the core).

10   In some embodiments, the disperse phase may have a core and shell construction, wherein the core and shell are made out of the same or different materials, or wherein the core is hollow. Thus, for example, the disperse phase may consist of hollow fibers of equal or random lengths, and of uniform or non-uniform cross section. The interior space of the fibers may be empty, or may be

15   occupied by a suitable medium which may be a solid, liquid, or gas, and may be organic or inorganic. The refractive index of the medium may be chosen in consideration of the refractive indices of the disperse phase and the continuous phase so as to achieve a desired optical effect (i.e., reflection or polarization along a given axis).

20   The geometry of the disperse phase may be arrived at through suitable orientation or processing of the optical material, through the use of particles having a particular geometry, or through a combination of the two. Thus, for example, a disperse phase having a substantially rod-like structure can be produced by orienting a film consisting of approximately spherical disperse phase particles

25   along a single axis. The rod-like structures can be given an elliptical cross-section by orienting the film in a second direction perpendicular to the first. As a further example, a disperse phase having a substantially rod-like structure in which the rods are rectangular in cross-section can be produced by orienting in a single direction a film having a disperse phase consisting of a series of essentially

30   rectangular flakes.

Stretching is one convenient manner for arriving at a desired geometry, since stretching can also be used to induce a difference in indices of refraction within the material. As indicated above, the orientation of films in accordance with the invention may be in more than one direction, and may be sequential or

5   simultaneous.

In another example, the components of the continuous and disperse phases may be extruded such that the disperse phase is rod-like in one axis in the unoriented film. Rods with a high aspect ratio may be generated by orienting in the direction of the major axis of the rods in the extruded film. Plate-like structures

10   may be generated by orienting in an orthogonal direction to the major axis of the rods in the extruded film.

The structure in FIG. 2 can be produced by asymmetric biaxial orientation of a blend of essentially spherical particles within a continuous matrix. Alternatively, the structure may be obtained by incorporating a plurality of fibrous

15   structures into the matrix material, aligning the structures along a single axis, and orienting the mixture in a direction transverse to that axis. Still another method for obtaining this structure is by controlling the relative viscosities, shear, or surface tension of the components of a polymer blend so as to give rise to a fibrous disperse phase when the blend is extruded into a film. In general, it is found that

20   the best results are obtained when the shear is applied in the direction of extrusion.

Dimensional Alignment of Disperse Phase

Dimensional alignment is also found to have an effect on the scattering behavior of the disperse phase. In particular, it has been observed in optical bodies

25   made in accordance with the present invention that aligned scatterers will not scatter light symmetrically about the directions of specular transmission or reflection as randomly aligned scatterers would. In particular, inclusions that have been elongated through orientation to resemble rods scatter light primarily along (or near) the surface of a cone centered on the orientation direction and along the

30   specularly transmitted direction. This may result in an anisotropic distribution of scattered light about the specular reflection and specular transmission directions.

For example, for light incident on such an elongated rod in a direction
perpendicular to the orientation direction, the scattered light appears as a band of
light in the plane perpendicular to the orientation direction with an intensity that
decreases with increasing angle away from the specular directions. By tailoring the
5   geometry of the inclusions, some control over the distribution of scattered light can
be achieved both in the transmissive hemisphere and in the reflective hemisphere.

Dimensions of Disperse Phase

       In applications where the optical body is to be used as a low loss reflective
10   polarizer, the structures of the disperse phase preferably have a high aspect ratio,
i.e., the structures are substantially larger in one dimension than in any other
dimension. The aspect ratio is preferably at least 2, and more preferably at least 5.
The largest dimension (i.e., the length) is preferably at least 2 times the wavelength
of the electromagnetic radiation over the wavelength range of interest, and more
15   preferably at least 4 times the desired wavelength. On the other hand, the smaller
(i.e., cross-sectional) dimensions of the structures of the disperse phase are
preferably less than or equal to the wavelength of interest, and more preferably less
than 0.5 times the wavelength of interest.

20   **Volume Fraction of Disperse Phase**

       The volume fraction of the disperse phase also affects the scattering of light
in the optical bodies of the present invention. Within certain limits, increasing the
volume fraction of the disperse phase tends to increase the amount of scattering
that a light ray experiences after entering the body for both the match and
25   mismatch directions of polarized light. This factor is important for controlling the
reflection and transmission properties for a given application.

       The desired volume fraction of the disperse phase will depend on many
factors, including the specific choice of materials for the continuous and disperse
phase. However, the volume fraction of the disperse phase will typically be at least
30   about 1% by volume relative to the continuous phase, more preferably within the

range of about 5 to about 15%, and most preferably within the range of about 15 to about 30%.

Co-Continuous Phases

5   When the volume fraction for binary blends of high polymers of roughly equivalent viscosity approaches 50%, the distinction between the disperse and continuous phases becomes difficult, as each phase becomes continuous in space. Depending upon the materials of choice, there may also be regions where the first phase appears to be dispersed within the second, and vice versa. For a description

10   of a variety of co-continuous morphologies and for methods of evaluating, analyzing, and characterizing them, see Sperling and the references cited therein (L.H. Sperling, "Microphase Structure", Encyclopedia of Polymer Science and Engineering, 2nd Ed., Vol. 9, 760-788, and L.H. Sperling, Chapter 1 "Interpenetrating Polymer Networks: An Overview", Interpenetrating Polymer

15   Networks, edited by D. Klempner, L.H. Sperling, and L.A. Utracki, Advances in Chemistry Series #239, 3-38, 1994).

Materials having co-continuous phases may be made in accordance with the present invention by a number of different methods. Thus, for example, the polymeric first phase material may be mechanically blended with the polymeric

20   second phase material to achieve a co-continuous system. Examples of co-continuous morphologies achieved by blending are described, for example, in D. Bourry and B.D. Favis, "Co-Continuity and Phase Inversion in HDPE/PS Blends: The Role of Interfacial Modification", 1995 Annual Technical Conference of the Society of Plastics Engineers ANTEC, Vol. 53, No. 2, 2001-2009

25   (polystyrene/polyethylene blends), and in A. Leclair and B.D. Favis, "The role of interfacial contact in immiscible binary polymer blends and its influence on mechanical properties", Polymer, Vol. 37, No. 21, 4723-4728, 1996 (polycarbonate/polyethylene blends).

Co-continuous phases may also be formed in accordance with the present

30   invention by first by dissolving them out of supercritical fluid extractions, such as that disclosed for blends of polystyrene and poly(methyl methacrylate) in U.S.

4,281,084, and then allowing them to phase separate following exposure to heat and/or mechanical shear, as described by in N. Mekhilef, B.D. Favis and P.J. Carreau, "Morphological Stability of Polystyrene Polyethylene Blends", 1995 Annual Technical Conference of the Society of Plastics Engineers ANTEC, Vol. 53, No. 2, 1572-1579).

A further method of producing co-continuous phases in accordance with the present invention is through the creation of interpenetrating polymer networks (IPNs). Some of the more important IPNs include simultaneous IPNs, sequential IPNs, gradient IPNs, latex IPNs, thermoplastic IPNs, and semi-IPNs. These and other types of IPNs, their physical properties (e.g., phase diagrams), and methods for their preparation and characterization, are described, for example, in L.H. Sperling and V. Mishra, "Current Status of Interpenetrating Polymer Networks", Polymers for Advanced Technologies, Vol. 7, No. 4, 197-208, April 1996, and in L.H. Sperling, "Interpenetrating Polymer Networks: An Overview", Interpenetrating Polymer Networks, edited by D. Klempner, L.H. Sperling, and L.A. Utracki, Advances in Chemistry Series #239, 3-38, 1994). Some of the major methods for preparing these systems are summarized below.

Simultaneous IPNs may be made by mixing together the respective monomers or prepolymers, plus the crosslinkers and activators, of two or more polymer networks. The respective monomers or prepolymers are then reacted simultaneously, but in a non-interfering manner. Thus, for example, one reaction may be made to proceed by way of chain polymerization kinetics, and the other reaction may be made to proceed through step polymerization kinetics.

Sequential IPNs are made by first forming an initial polymer network. Then, the monomers, crosslinkers, and activators of one or more additional networks are swollen into the initial polymer network, where they are reacted in situ to yield additional polymer networks.

Gradient IPNs are synthesized in such a manner that the overall composition or crosslink density of the IPN varies macroscopically in the material from one location to another. Such systems may be made, for example, by forming a first polymer network predominantly on one surface of a film and a second

polymer network predominantly on another surface of the film, with a gradient in composition throughout the interior of the film.

Latex IPNs are made in the form of latexes (e.g., with a core and shell structure). In some variations, two or more latexes may be mixed and formed into

5   a film, which crosslinks the polymers.

Thermoplastic IPNs are hybrids between polymer blends and IPNs that involve physical crosslinks instead of chemical crosslinks. As a result, these materials can be made to flow at elevated temperatures in a manner similar to that of thermoplastic elastomers, but are crosslinked and behave as IPNs at the

10   temperatures of normal use.

Semi-IPNs are compositions of two or more polymers in which one or more of the polymers are crosslinked and one or more of the polymers are linear or branched.

As indicated above, co-continuity can be achieved in multicomponent

15   systems as well as in binary systems. For example, three or more materials may be used in combination to give desired optical properties (e.g., transmission and reflectivity) and/or improved physical properties. All components may be immiscible, or two or more components may demonstrate miscibility. A number of ternary systems exhibiting co-continuity are described, for example, in L.H.

20   Sperling, Chapter 1 "Interpenetrating Polymer Networks: An Overview", Interpenetrating Polymer Networks, edited by D. Klempner, L.H. Sperling, and L.A. Utracki, Advances in Chemistry Series #239, 3-38, 1994).

Characteristic sizes of the phase structures, ranges of volume fraction over which co-continuity may be observed, and stability of the morphology may all be

25   influenced by additives, such as compatibilizers, graft or block copolymers, or reactive components, such as maleic anhydride or glycidyl methacrylate. Such effects are described, for example, for blends of polystyrene and poly(ethylene terephthalate) in H.Y. Tsai and K. Min, "Reactive Blends of Functionalized Polystyrene and Polyethylene Terephthalate", 1995 Annual Technical Conference

30   of the Society of Plastics Engineers ANTEC, Vol. 53, No. 2, 1858-1865.

However, for particular systems, phase diagrams may be constructed through

-23-

embodiment, the DRMF of the present film as herein described may be used as the reflective element in a non-polarized light fixture. The DRMF may additionally be metallized either by vapor coating or laminating a reflective metal to the back side of the DRMF to improve total reflectivity.

5   Many applications require polarized light to function properly. Examples of such an applications include optical displays, such as liquid crystal displays (LCDs), which are widely used for lap-top computers, hand-held calculators, digital watches, automobile dashboard displays and the like, and polarized luminaires and task lighting which make use of polarized light to increase contrast

10   and reduce glare. For applications where polarized light is desired, the light fixture generally consists of a housing containing a light source and a polarizing element, and may additionally include a reflecting element and/or a diffusing element. The light source may be any of the light sources described above (e.g., a fluorescent lamp), but is preferably a diffuse light source which emits light having a high

15   degree of scatter or randomization with respect to both polarization and direction. The reflecting element, if present, may be any of the reflective materials described above, or may also be the BRMF of the present invention. The polarizing element may include any polarizer, including absorbing dichroic, thin film dielectric or cholesteric polarizers, but is preferrably the multilayer birefringent reflective

20   polarizer described in WO 95/17303 and WO 96/19347.

          Absorptive polarizers typically use dichroic dyes which transmit light of one polarization orientation more strongly than the orthogonal polarization orientation. When an absorptive polarizer is used in a display or polarized light fixture, for example, the absorbed light does not contribute to the illumination, and

25   thus to the overall brightness, of the LCD or luminaire. The use of such polarizers in lighting applications is described in U.S. Pat. Nos. 3,124,639 (Kahn), 3,772,128 (Kahn), and 4,796,160 (Kahn), and in U.S. Pat. Nos. 5,184,881 (Karpen) and 5,359,498 (Karpen). Vacuum deposited, thin film dielectric polarizers are not absorbing, as are dichroic polarizers, but do suffer other disadvantages, such as

30   poor angular response and poor spectral transmission for non-designed wavelengths. In addition, they are conventionally coated onto stable substrates,

such as bulk optical glass or polymer substrates, and this may render them too
bulky and heavy for use in lighting applications requiring light weight and small
profile. For some lighting applications, these polarizers may be combined with a
suitable light source and the DRMF of the present invention to provide a polarized
5   light fixture.

The preferred reflective polarizers specularly transmit light of a desired
polarization and reflect light of another polarization. Light produced by a diffuse
source is randomly polarized and therefore has polarization components (a) and (b)
present. This light is incident on the reflective polarizing element. The reflective
10   polarizing element is adapted to transmit light having a first polarization
component (polarization component (a) in this example), and reflect light having
the orthogonal polarization component ((b) in this example). Consequently, light
of polarization component (a) is transmitted by the reflective polarizing element,
while light of polarization component (b) is reflected back into the light fixture
15   where it is randomized. Some of the initially rejected light is thus converted into
the desired polarization and is specularly transmitted through the reflective
polarizing element. This process continues, and the repeated reflections and
subsequent randomization of light of the undesired polarization increases the
amount of light of the desired polarization that is emitted from the diffuse
20   polarized light fixture. The result is a very efficient system for producing light of a
desired polarization. The repeated reflections and randomizations effected by the
combination of the diffuse source and the reflective polarizing element form an
efficient mechanism for converting light from state (b) to state (a). The system is
efficient in the sense that light which would otherwise have been absorbed, and
25   therefore unavailable, is instead converted to the desired polarization. A light
fixture using such a polarizing element thus makes much more efficient use of the
light emitted from the source, since light of the rejected polarization is reflected
back into the source and randomized. As a result, the total amount of light emitted
from the fixture in the desired polarization is increased. The use of a multilayer
30   birefringent reflective polarizing film (RPF) in lighting applications is described in
applicants commonly assigned U.S. Patent Application Serial Numbers 08/418,009

and 08/479,319, also incorporated herein by reference. These applications describe the use of the multilayer RPF in lighting applications, especially in LCD displays and polarized luminaires. The reflective polarizing element of these applications transmits light of a desired polarization and _specularly_ reflects light of another

5   polarization back into the diffuse source where it is randomized. When a multilayer RPF is used in this way, a separate diffuser film is typically used in luminaires or task lighting applications so that the light source is not directly visible. A reflective element is preferably also included in these polarized light fixtures, and the reflective element may comprise the BRMF of the present invention or any

10   other suitable reflective surface that either randomizes the light reflected from the RPF or reflects the reflected light back into a diffusing source where it can be randomized and partially converted into the correct polarization to be transmitted by the polarizing element.

       The DRPF of the present invention functions similar to the multilayer RPF

15   to increase the amount of light of the desired polarization that is emitted by the polarized light fixture, however, the initially rejected light of the wrong polarization is _diffusely_ reflected back into the light fixture where it may be randomized, partially converted to light of the correct polarization, and specularly transmitted through the polarizing element. The diffuse reflective polarizing film

20   (DRPF) of the present invention is translucent so that a separate diffuser is not needed. When combined with the light source to make a diffuse reflecting polarized light fixture, a reflecting element is preferably also included to direct the reflected light back to the source and/or aid in the randomization and partial conversion of the reflected light into light of the correct polarization to be

25   transmitted by the polarizing element. The reflecting element may be any suitable reflective material, as described above, and in particular may be the DRMF of the present invention. As such, the DRMF of the present invention may be used in one embodiment as the reflecting element and the DRPF of the present invention may be used as the polarizing element and/or the diffusing element.

30   In the light fixtures described herein, the light source may be coupled with the polarizing element and reflecting element in a variety of configurations. Some

of the configurations will be described with respect to using the diffuse reflecting polarizing film (DRPF) of the present invention as the polarizing element and the diffuse reflecting mirror film (DRMF) of the present invention as the reflecting element, but it should be recognized that various combinations of DRPF with other

5   materials as the reflecting element and DRMF with other materials as the polarizing element are envisioned. In one configuration, the DRPF may be wrapped around such that it completely encloses the diffuse source. A separate reflector may be used in addition to the light source and DRPF. The reflector may be a diffuse reflective film (DRMF) which randomizes the light of polarization (b)

10   that is reflected from the DRPF, or it may be a specular reflector which redirects light to the light emitting region of a diffuse randomizing light source. The DRMF may be oriented around one side of the light source and may be laminated or otherwise attached to the light source. In this configuration, the DRPF may also be laminated or otherwise attached so that it partially encloses the other side of the

15   light source.

The embodiments of the present polarized light source using the DRPF have several advantages. The reflection and randomization process achieved with the light source and DRPF gives a polarized light fixture that is very efficient. The broadband reflectivity provided by the DRPF means that efficiency is achieved

20   over a broad spectral range. In addition, the DRPF provides high off-angle reflectivity of the rejected polarization. These features make the DRPF/diffuse source combination useful over a broader range of the optical spectrum and over a broader range of angles than the embodiments incorporating bulk optic components. In addition, the DRPF is lightweight, thin and flexible, which makes

25   it good for applications requiring low bulk and light weight. The DRPF also conforms well to the lamp surface and could be incorporated into the lamp manufacture. Furthermore, since the DRPF is a diffuse reflector, its opaque appearance obviates the need for a separate diffuser film that is typically used in polarized luminaires and task lighting fixtures to obscure the light source from

30   direct viewing.

In yet another application, optical films of the present invention may be used to generate polarized light used in smoke detection systems or in the analysis of the polarization of light scattered from smoke particles, including those smoke detection systems which attempt to define the nature or origin of the combustion as

5   taught by U.S. 5,576,697 (Nagashima et al.).

Light Extractors

The optical films of the present invention may be used as light extractors in various optical devices, including light guides such as the Large Core Optical Fiber

10   (LCOF) illustrated in FIG. 8. The LCOF 50 uses very efficient total internal reflection (TIR) to guide light substantial distances from an illuminator or light source 52. However, when the optical films of the present invention are applied as an external cladding 54, they upset the light guiding at the fiber-to-air interface, thereby ejecting light out into the surroundings. This feature may be used

15   advantageously in various remote source lighting applications, such as architectural highlighting, decorative lighting, medical lighting, signage, visual guidance (e.g., on landing strips or in aisles for airplanes or theatres), display (e.g., instrument displays, especially those in which excessive heating is a problem) and exhibit lighting, roadway lighting, automotive lighting, downlighting, task lighting, accent

20   lighting, and ambient lighting. In some applications, the films of the present invention may be applied as a cladding at multiple locations along the length of the fiber, thereby illuminating multiple locations from a single light source. Furthermore, since these systems are commonly equipped with UV and IR filters, the lighting produced by such systems will not degrade UV sensitive materials, nor

25   will the light guides heat up with use.

The films of the present invention can also be made to extract only a single polarization of light, thereby creating a polarization-specific source. With proper configuration of the light fiber system, substantially all of the light injected into the fiber will eventually make its way through the extractor in the desired polarization.

30   Polarization-specific sources can be made, for example, by using an optical film of the present invention which is a strong diffuse scatterer for light of a first

polarization, but is a non-scattering, specular material which maintains a total internal reflection (TIR) cladding-to-surface interface for light of a second polarization. Such a system is described in Example 134.

Suitable light guides for use in the present invention include both side
5   emitting and end emitting fibers. The light guides themselves may be glass or plastic and may be of varying diameters, depending on such factors as the required efficiency at collecting light, required flexibility, and whether the light guides are to be used alone or in bundles. The light guides may also be fiber optic light guides or prism light guides, with the later being more suitable for large scale
10   applications, and the former being more suitable for smaller scale applications where cost per lumen is less important.

Commercially available light guides that are suitable for use in the present invention include those made from films of low Tg acrylic polymers, such as the optical lighting film available commercially from 3M under the tradename Scotch
15   Optical Lighting Film (SOLF). Such film, which acts like a mirror towards light striking it at certain angles, is a transparent plastic film which has a prismatic surface (typically microreplicated) on one side and a smooth surface on the other. The film is commonly used in conjunction with a tubing or backing of a transparent or opaque plastic or metal. Other suitable light guides include the
20   linear illumination fiber optics available commercially from Lumenyte under the tradename Fiberescent™, and the end-emitting fibers available commercially from Fiberstars under the tradename FiberSpots™.

Various light sources may be used in conjunction with the light guides made in accordance with the present invention, depending on the application to
25   which the light guide is directed. Such sources are described, for example, in Lighting Futures, Vol. 1, No. 3 (1995), a publication of the Lighting Research Center, Rensselaer Polytechnic Institute, Troy, N.Y. Typically, a low voltage 20-75 watt MR16 lamp used in conjunction with a fiber optic system will be suitable for applications such as museum, display and accent lighting, while a 70-250 watt
30   metal halide lamp, used in conjunction with a fiber optic or prism light guide system, is suitable for applications such as architectural or outdoor lighting

applications. For applications requiring 250 watts or greater, metal halide or high pressure sodium lamps may be used in conjunction with prism light guide systems. Other suitable light sources include 60 watt xenon metal halide lamps, commercially available from General Electric Company, Danbury, Connecticut,

5   which are particularly useful for automotive applications, and sulfur lamps, commercially available from Fusion Lighting, Rockville, MD, which have been used successfully on an experimental basis in prism light guide systems. Compact and tubular fluorescent lamps may also be used where a larger diffuse light source is needed. Sunlight may also be used with fiber optic or prism light guide systems,

10   and in conjunction with mirrors or lenses, as part of a sunlight harvesting system.

In some backlight display devices, such as those used in avionics applications where high levels of ambient light impinge on the front surface of the device, high intensities radiating from the display are required to provide sufficient contrast to the display. Consequently, excessive heating of the backlight assembly

15   in such systems can occur unless means are provided to dissipate the unwanted heat. A variety of means are used in the art to eliminate the heat, such as the use of cold mirrors and filters and other means.

In most new aircraft, ambient sunlight potentially reduces contrast to the flat panel displays used, and spatial requirements for the ensemble of displays are

20   critical desgin parameters. Therefore, in one form of the present invention, light is transported to the display(s) via fiber optics from a remotely located, but intense, source, where the latter can be cooled efficiently and the undesired heat not affect the operation of the display device. Since these displays typically work on the basis of polarized light propagating through a liquid crystal display, the optical

25   films of the present invention may be used in such systems as light extractors of substantially one polarization. The second polarization would continue to reflect inside the optical fiber until its polarization is converted to the first polarization and can be emitted from the light extractor at the places where the light is needed.

The light directing material

As described above with respect to Figures 4A and 4B, in one embodiment the optical body of the present invention demonstrates specular transmission of light polarized in the index match direction (in other words, perpendicular to the

5   oriented direction), and diffuse reflection of light polarized in the index mismatch direction (in other words, parallel to the oriented direction). The diffuse polarizer of the present invention, or any other polarizer exhibiting this same functionality, can thus be referred to as a diffusely reflecting, specularly transmitting (DRST) polarizer. A DRST polarizer has utility in polarized light fixtures and liquid crystal

10   displays (LCDs). An exemplary emodiment of such a display incorporating a DRST polarizer is described in more detail below with respect to Figure 14.

A DRST polarizer can also be combined with light directing materials to produce desirable effects. These combined direction control polarizers, as they will hereinafter be referred to, are also advantageous for use in LCD applications as

15   well as lighing fixtures such as the luminaires used in office lighting and task lighting.

The purpose of light directing material is to enable light which would have exited at angles where light is not useful in certain applications, or light having the wrong polarization to be used by the light fixture or LCD module, to be redirected

20   or recycled into angles and polarizations that are useful. For many applications, such as in a LCD, for example, it is generally desirable that light be emitted generally toward the direction of a user. Thus, light exiting the LCD at very shallow angles to the plane of the LCD is not useful, as a user is typically not in such a position to view the display. It is desirable, therefore, to somehow redirect

25   or recycle this light into a useable viewing zone. This is the function of the light directing material.

The preferred light directing material 113 will now be described with respect to Figures 10 and 11. Figure 10 shows a side view of one preferred light directing material, while Figure 11 shows a graph illustrating the performance of

30   the preferred light directing material shown in Figure 10.

Figure 10 is an enlargement of a structured surface material that is the preferred embodiment of the light directing material in the present invention. Structured surface material 218 has a smooth side 220 and a structured side 222. Structured side 222 includes a plurality of structures, such as structure 224. Several

5   different structure types are possible. For example, the structures can be isosceles prisms, such as those shown in Figure 10, saw tooth structures, structures having rounded peaks and/or rounded valleys (such as those described in U.S. Patent Numbers 5,394,255 and 5,552,907) or other structure shapes as needed for the particular final application in which the light directing material will be used.

10   The preferred included angle 223 of the structure will vary depending upon where the light is to be directed in the final application of the light directing material. Generally, included angles in the range of 60-120 degrees are preferred, with included angles in the ranges of 70-100 degrees, 80-90 degrees, 85-95 degrees or about 90 degrees being preferred for different applications.

15   Structured surface material 218 may be made of any transparent material having an index of refraction greater than that of air, but, in general, the materials with higher indices of refraction are preferred. Polycarbonate, which has an index of refraction of 1.586, has shown to work very effectively.

Exemplary structured surface materials which may be appropritae for

20   different applications include Brightness Enhancement Film (BEF I or BEF II), Transparent Right Angle Film (TRAF), Optical Lighting Film (OLF or SOLF), or Diamond Grade Sheeting, all of which are available from the assignee of the present invention, Minnesota Mining and Manufacturing Company (3M) St. Paul, MN. Other exemplary structured surface materials include the rounded peak/valley

25   films described in the above-mentioned U.S. Patent Numbers 5,394,255 and 5,552,907, available from Sekisui Chemical Co. Ltd., Japan.

Although any of the above variations of the light directing material may be appropriate or preferred for different end uses, for purposes of illustration, the structured surface material 218 will be assumed to made of polycarbonate and

30   include isosceles prism shaped structures having included angles of between 85-95 degrees.

Figure 11 illustrates the operation of the illustrative structured surface material 218. Figure 11 is a graph having two axes 226 and 228. These axes represent the angle that a light ray makes to a normal to smooth surface 220. Specifically, axis 226 represents the angle that the light ray makes when the direction of the light ray is projected into a plane parallel to the linear extent of the structures on structured surface 222. Similarly axis 228 represents the angle that the light ray makes to a normal to smooth surface 220 when the direction of the light ray is projected into a plane perpendicular to the linear extent of the structures on structured surface 222. Thus a light ray striking perpendicular to smooth surface 220 would be represented by the origin, labeled 0 degrees, of the graph of Figure 8. As may be seen, Figure 8 is divided into regions 230, 232, and 234. Light striking at angles that fall within region 230 will enter structured surface material 218 but be totally internally reflected by structured surface 222 so that they pass through smooth surface 220 a second time and reenter the optical cavity. Light rays striking smooth surface 220 at an angle such that they fall in region 232 or 234 will be transmitted but refracted to a different angle with respect to the normal. As may be seen from Figure 8, which represents the performance of polycarbonate with a 90 degree included prism angle, any light ray striking smooth surface 220 at an angle of less than 9.4 degrees to the normal, will be reflected. The angle to the normal to smooth surface 220 below which rays striking smooth surface 220 are reflected by optically structured material 213 will hereinafter be called the cutoff angle.

Returning to Figure 10, four exemplary light rays are shown emanating from an optical cavity, which is not shown. The first, light ray 236, approaches smooth surface 220 at a grazing angle, i.e., an angle to the normal approaching 90 degrees. If light ray 236 makes an angle of 89.9 degrees to the normal to surface 220 when it strikes structured surface material 218, it will be refracted such that it makes an angle of 39.1 degrees to the normal as it travels through structured surface material 218. Upon reaching structured surface 222, it will be refracted again. Because of the structures on structured surface 222, it will be refracted so

that again it will make a smaller angle to the normal to structured surface 220. In the example it will make an angle of 35.6 degrees.

Light ray 238 approaches smooth surface 220 at an angle much closer to the cut off angle. It also is refracted as it passes through smooth surface 220, but to a

5   lesser extent. If light ray 238 approaches smooth surface 220 at an angle of 10 degrees to the normal to smooth surface 220, it will emerge from structured surface 222 at an angle of 37.7 degrees to the normal to smooth surface 220 but on the opposite side of that normal.

Light ray 240 approaches at an angle less than the cut off angle and is

10   totally internally reflected twice by structured surface 222 and exits back out the smooth side 220.

Finally, light ray 242 approaches smooth surface 220 at an angle similar to that of light ray 238, but in a location such that it is totally internally reflected by one side of a prism on structured surface 222 but not by the second side. As a

15   result it emerges at a large angle to the normal to smooth surface 220. Because such a reflection only occurs to a light ray that is travelling in a direction that forms a high incidence angle to the side it strikes, the prisms provide a very small cross section to such rays.

A fifth class of light ray is not shown in Figure 10. This is the set of light

20   rays that are reflected by smooth surface 220 and do not enter structured surface material 218. Such light rays simply join the others that are reflected back into the optical cavity. As may be seen from this discussion, light that, absent structured surface material 218, would have emerged from the display at a high angle to the axis of the display, where the axis of the display is taken to be the normal to

25   smooth surface 220, is redirected into a direction closer to that axis. A small amount of light will be directed out at a large angle to the axis. Thus, we may say that light that enters structured surface material 218 through smooth surface 220 with an angle of incidence greater than a predetermined angle is directed into an output wedge that is narrower than the input wedge and the majority of the light

30   that enters structured surface material 218 through smooth surface 220 at an angle

of incidence of less than that predetermined angle will be reflected back out the smooth side 220 of the structured surface material 218.

Although the preferred structured surface material 218 functions as a geometric optic, it is well known that diffractive or holographic optical elements

5   may be designed to effectively mimic the light directing qualities exhibited by geometric optics. Therefore the term structured surface should be understood to include both geometric and diffractive optical systems that serve to transmit light within a desired angular zone and to reflect light which would not exit the light directing film within a desired angular zone.

10

The direction control polarizer

The combination of a DRST polarizer with the illustrative light directing material will now be described with respect to Figures 12A, 12B, 13A and 13B. Figures 12A and 12B show the reflectance and the transmittance properties,

15   respectively, of a a first preferred embodiment of the direction control polarizer 110. In this embodiment, the DRST 116 is placed below the light directing material 113, and light is incident upon the combination from the DRST side. Due to the inherent polarizing nature of an array of structures, generally speaking, optimum performance is achieved when the axes of orientation of the prisms run

20   parallel to the direction in which the DRST polarizer was oriented.

In Figure 12A, ray 133 is of the polarization that is specularly transmitted by DRST 116, but is traveling in a direction such that it is totally internally reflected to become ray 135 by light directing material 113. Ray 137 is of the polarization that is diffusely reflected by DRST 116, and thus forms diffusely

25   reflected reflected rays 139, 141 and 143.

In Figure 12B, ray 145 is of the polarization that is specularly transmitted by DRST 116, and is traveling in a direction such that it is refracted to become ray 147 by light directing material 113. The result of the reflectances and transmittances shownn in Figures 12A and 12B mean that light of one polarization

30   is transmitted by the direction control polarizer, and that light that is transmitted is directed into a desired angular zone, whereas light of the other polarization is

diffusely reflected, and light which would not exit the light directing material within the desired angular zone is also reflected.

Figures 13A and 13B show the reflectance and the transmittance properties, respectively, of a second preferred embodiment of the direction control polarizer.

5   In this embodiment, the DRST 116 is placed above the light directing material 113, and light is incident upon the combination from the smooth side of the light directing material 113. In Figure 13A, ray 149 is traveling in a direction such that it is refracted by light directing material 113. However, ray 149 is also of the polarization that is diffusely reflected by DRST 116 into rays such as 151, 153 and

10 155. Rays 151 and 153 are scattered back toward the light directing material 113, and are incident upon the structured surface side at angles such that they are refracted through the structured side and exit out the smooth side. Ray 155 is scattered back toward light directing material 113. However, this ray is incident   (upon the structured side at an angle where it is completely reflected off of the

15 structured surface back toward the DRST 116. Ray 155 is of the polarization that is diffusely reflected by DRST 116 (only one reflected ray is shown, however). The so-reflected ray is shown exiting out the side of the direction control polarizer and is one example of how some light can be "lost" in this embodiment of the direction control polarizer. Rays 157 and 159 strike light directing material 113 at

20 angles below the cutoff angle, and are therefore reflected.

In Figure 13B, ray 165 is traveling in a direction such that it is refracted by structured surface material 113. Ray 165 is also of the polarization that is specularly transmitted into ray 167 by DRST 116. The result of the reflectances and transmittances shown in Figures 13A and 13B mean that light of one

25 polarization is transmitted by the direction control polarizer, and that light that is transmitted is directed into a desired angular zone, whereas light of the other polarization is diffusely reflected, and light which would not exit the light directing material within the desired angular zone is also reflected.

Displays incorporating the DRST and the direction control polarizer

Several display configurations incorporating the DRST polarizer alone or the direction control polarizers described above are possible. A side view of one such display incorporating the DRST polarizer is shown schematically in Figure 14. This display includes a display module 142, DRST polarizer 116 and optical cavity 140. Preferably, the optical cavity is a diffusely reflecting optical cavity such as a light guide coated with diffusely reflecting dots, an electroluminescent panel, or by other technicques known in the art. Light that is emitted by the optical cavity is illustrated by ray bundle 38. This ray bundle is incident on the DRST polarizer 116 which specularly transmits light having a first polarization orientation referred to as "(a)" and diffusely reflects light having the orthogonal polarization orientation "(b)". Consequently, a certain amount of light, depicted by ray bundle 42, will be transmitted by the DRST polarizer 116 while the remaining light will be reflected as indicated by ray bundle 40.

The light having polarization state (b) reflected by the DRST polarizer 116 reenters the optical cavity 140 where it strikes the diffusely reflective surfaces within the optical cavity. The diffusely reflective surfaces within the optical cavity serve to alter the polarization state and the direction of at least some of the light reflected by the optical cavity 140. Thus, at least some of the light of polarization (b) reflected by the DRST polariazer 116 is converted to polarization (a) by the diffusely reflecting surfaces within the optical cavity. This recirculation, or recycling process is depicted as path 48. The multiple recirculations effected by the combination of the optical cavity 140 and the DRST polarizer 116 form an efficient mechanism for converting light from state (b) to state (a) for transmission of ray 45 by the DRST and ultimate transmission of rays 47 to the viewer 146.

In another display embodiment, the apparent brightness of the display may be increased by the use of a direction control polarizer such as that described above with respect to Figures 12A, 12B, 13A and 13B. Such a display is shown schematically in Figure 15. Figure 15 shows a display 164 which has three primary components. These are the display module 142, the direction control polarizer 110 and the optical cavity 140.

The left half of Figure 15 shows a portion of the display 164 without the direction control polarizer 110 material to permit a comparison of the displays performance with and without the direction control polarizer 110. In general, the light emerging from a unit area of the optical cavity 140 depicted by ray bundle

5   148 will be randomly polarized and will include both polarizations (a) and (b). Approximately half of this light, light of state (b), is absorbed by a dichroic absorptive polarizer 150 that forms a part of the display module 142. The remainder of the light, state (a), is passed through the dichroic absorptive polarizer 150 and is used to create the images on the display. The light emerging from the

10   display module 142, depicted by ray bundle 152, thus contains light of states (a) only. However, only a portion of this light of state (a) is directed within an angular zone that is useful for the observer 146. Thus, less than half of the light provided by optical cavity 140 (the portion of state (a) that is within a useable angular zone of the observer actually contributes to the brightness of the display as viewed by

15   observer 146.

The direction control polarizer operates to make more efficient use of the light made available by optical cavity 140. If the same unit amount of light, depicted by ray bundle 154, is directed to the direction control polarizer 110, light of state (a) will pass through the direction control polarizer 110 on the first pass.

20   This light will have the correct polarization to match the transmission axis of the dichroic absorptive polarizer in the display module, and is depicted as ray bundle 161. The remaining light of state (b) will be reflected back into the optical cavity by the direction control polarizer 110.

At least some of this light reflected by the direction control polarizer will

25   be altered in terms of polarization to state (a) and also in direction by the optical cavity 140. Thus, this light will emerge from the optical cavity with states (a) and (b) as indicted by ray bundle 157. The recirculated light of state (a) will then be added to the originally transmitted light as depicted by ray bundle 160. Thus, the total amount of light depicted by ray bundle 160 and ray bundle 161 is increased

30   by this recirculation or recycling effect. Because only light of the correct polarization to match the transmission axis of the dichroic absorptive polarizer

(state (a)) is passed through the direction control polarizer 110, much more of the light emitted from the display, depicted by ray bundle 163, is directed toward the observer 146. In addition, because light of state (b) is reflected by the direction control polarizer 110, very little is absorbed by the dichroic absorptive polarizer

5   150. The result is a display in which the amount of light emerging from the display, depicted by ray bundle 163, may be 70 percent brighter than the amount of light indicated by ray bundle 152.

Figure 16 shows a display 179 where direction control polarizer 110 is incorporated into a liquid crystal display. Light directing material 113 is located

10   between the optical cavity and the DRST polarizer 116 such that from the optical cavity is incident on the smooth side of the light directing material 113. Together these two components along with the gap 181 make up the direction control polarizer 110. In use, the optical cavity 140 will provide light for the display and will also act to reorient the polarization and direction of light returned from the

15   direction control polarizer 110 as discussed above. One difference between the display embodiment shown in Figure 16 and that of Figure 15 is that light approaching the light directing material 113 at an angle less than the cuttoff angle 134 is returned to the optical cavity by total internal reflection regardless of its state of polarization (see Figure 13A). Another difference is that the light

20   transmitted by light directing material 113 passes through the DRST polarizer 116 at near normal angles (see Figure 13B).

Two dimensional control of the rays exiting the direction control polarizer can be achieved using the alternate preferred display configuration 192 shown in Figure 17. There, two light directing materials 113 and 182, each having a

25   structured surface 112 and 184, respectively, are proximate to each other and to a DRST polarizer 116. These three elements comprise the direction control polarizer 111. Although in Figure 17 the two light directing materials are shown above the DRST polarizer 116, it shall be understood that the DRST polarizer 116 could also be placed between or below the light directing materials 112 and 182

30   without departing from the scope of the present invention. Two dimensional control is achieved by crossing the axes of orientation of the structured surfaces

112 and 184. The axes may be oriented anywhere between 60-120 degrees, 80-100 degrees, 85-95 degrees or at about 90 degrees depending upon the particular display application and associated polarization requirements.

5   In operation, using the light directing materials described above with respect to Figures 10 and 11, first light directing material 182 results in a viewing zone of approximately 70 degrees in the Y, Z plane and 110 degrees in the X, Z plane. The light exiting the first light directing material 182 then becomes the source for the second light directing material 113, whose structured surface 112 has a different axes of orientation than does the structured surface 184 of light directing

10   material 182. If the axes of the two light directing materials 113 and 184 are oriented at 90 degrees, for example, light directing material 113 operates on the light within the 110 degree angle of the X, Z plane and compresses the viewing angle in the X, Z plane to a narrower field of something less than 70 degrees, thereby further increasing brightness.

15   Figure 18 shows test results of the relative screen brightness of a standard LCD panel illuminated by a standard optical cavity for various combinations of DRST polarizer and light directing material. The screen brightness at various viewing angles, taken in a plane perpendicular to the stretched direction of the DRST polarizer, was measured relative to screen brightness at zero degrees

20   (normal) viewing angle with no DRST polarizer or light directing material being present in the system. Curve 169 in Figure 18 is the relative brightness at various viewing angles, measured relative to a viewing angle of zero degrees, of the standard display and optical cavity used in the tests without any optical body, such as a DRST polarizer, or any light directing optically structured layer being present.

25   Curve 168 is the relative brightness for the display shown schematically in Figure 14, wherein only DRST polarizer 116, acting as a reflective polarizer, is present between optical cavity 140 and liquid crystal display module142. Curve 166 is

the relative brightness for the display shown in Figure 15, wherein a light directing material is laminated to the DRST polarizer of the present invention. Curve 164 is the relative brightness for an arrangement wherein the DRST polarizer and the light directing material are present in the display, but wherein the

5   light from the optical cavity passes through the DRST before passing through the light directing material. Curve 162 is the relative brightness for the display shown in Figure 16, wherein DRST polarizer 116 and the light directing material 113 are present in the display, and wherein the light from optical cavity 140 passes through DRST polarizer 116 before passing through the light directing material

10   113. It will be noted that the addition of the light directing material, whether it be attached to the DRST polarizer without a gap as in curve 166, or present but separated from the optical body by a gap, as in curves 164 and 162, has the effect of brightening the screen at lower viewing angles and dimming it at larger viewing angles. This may be desirable, depending upon the range of viewing angles

15   contemplated in the intended use. The presence of the DRST polarizer by itself, with no light directing material present, provides, on the other hand, a more widely distributed increase in brightness, with less brightness at lower viewing angles but greater brightness at larger viewing angles.

Over-all screen brightness will also depend on the type of optical cavity

20   used, for example, whether an electroluminescent backlight or a standard backlight is used. The reflectance and losses of each type of optical cavity effects the overall brightness increase that can be achieved. In general, the gain of the display system is dependent on the efficiency of both the DRST polarizer and the optical cavity. Performance is maximized with a highly reflective optical cavity consistent with

the requirement of alteration of the polarization and direction of light, and a very low loss DRST polarizer .

When separate direction control films are coupled to the DRST polarizer, they may be either optically coupled or they may be adjacent sheets that are not optically coupled. A unitary, optically coupled structure of the DRST polarizer and light directing material may be formed by various known techniques of attaching two films, such as by heat lamination or adhering the films with an indexing matching adhesive. Alternately, a unitary structure of the DRST polarizer and light directing material may be formed by embossing the light directing structure directly on the surface of the DRST polarizer, such as embossing structure on the skin layer, if present, or the light directing structure may be cast and cured directly on the surface of the reflective polarizer wherein the reflective polarizer acts as the substrate in a process such as is described in United States Patent 5,175,030. Various combinations of direction control films or embossed or cast structured surfaces are contemplated. For example, the direction control film that is laminated or otherwise adhered to the DRST polarizer surface, or the directly structured light controlling surface of the DRST polarizer, may be a two-dimensional structure, or it may be a linearly structured surface with a separately linearly structured direction control film that is crossed at some angle, preferably 90 degrees, to the linearly structured surface of the DRST polarizer or combined DRST polarizer/linearly structured film surface. Furthermore, a linearly structured surface may be laminated, embossed, or cast and cured on one surface of the DRST polarizer, and another linearly structured surface may be laminated, embossed, or cast and cured at some crossed angle, preferably 90 degrees, on the opposite surface of the DRST polarizer. Whether present as separate films or a unitary structure, the linearly structured light control surfaces may be at any angle to each other, and at any angle to the polarizing direction of the DRST polarizer. Similarly, when used in a display, the combination of DRST polarizer and light controlling structure(s) may be at any angle to the display polarizer, so that the first light controlling structure, DRST polarizer, optional second light controlling structure, and display polarizer may be at any angle or combination of angles with

respect to each other. In the displays shown and described above, the direction control polarizer could be laminated or otherwise similarly adhered to or attached to the optical cavity and/or to the rear of the display module. Laminating the direction control polarizer to the optical cavity or the display module eliminates the air gap between them and thus reduces surface reflections which would otherwise occur at the air/reflective polarizer boundary. These reflection reduce the total transmission of the desired polarization. By attaching the reflective polarizer to the optical cavity or the display module, the surface reflections are reduced and total transmission of the desired polarization is increased. If the reflective polarizer is not so attached to the optical cavity or the display module, use of an anti-reflective (AR) coating may be desirable.

In the case shown in Fig. 16, it may not possible to laminate the reflective polarizer to the structured side of the structured surface material. In this case, it may be desirable to use an AR coated reflective polarizer to reduce surface reflections at the air/reflective polarizer interface.

Overview of Examples

The following Examples illustrate the production of various optical materials in accordance with the present invention, as well as the spectral properties of these materials. Unless otherwise indicated, percent composition refers to percent composition by weight. The polyethylene naphthalate resin used was produced for these samples using ethylene glycol and dimethyl-2,6-naphthalenedicarboxylate, available from Amoco Corp., Chicago, Illinois. These reagents were polymerized to various intrinsic viscosities (IV) using conventional polyester resin polymerization techniques. Syndiotactic polystyrene (sPS) may be produced in accordance with the method disclosed in U. S. Patent 4,680,353 (Ishihara et al). The examples includes various polymer pairs, various fractions of continuous and disperse phases and other additives or process changes as discussed below.

Stretching or orienting of the samples was provided using either conventional orientation equipment used for making polyester film or a laboratory

batch orienter. The laboratory batch orienter used was designed to use a small piece of cast material (7.5cm by 7.5cm) cut from the extruded cast web and held by a square array of 24 grippers (6 on each side). The orientation temperature of the sample was controlled a hot air blower and the film sample was oriented through a

5 mechanical system that increased the distance between the grippers in one or both directions at a controlled rate. Samples stretched in both directions could be oriented sequentially or simultaneously. For samples that were oriented in the constrained mode (C), all grippers hold the web and the grippers move only in one dimension. Whereas, in the unconstrained mode (U), the grippers that hold the

10 film at a fixed dimension perpendicular to the direction of stretch are not engaged and the film is allowed to relax or neckdown in that dimension.

Polarized diffuse transmission and reflection were measured using a Perkin Elmer Lambda 19 ultraviolet/visible/near infrared spectrophotometer equipped with a Perkin Elmer Labsphere S900-1000 150 millimeter integrating sphere

15 accessory and a Glan-Thompson cube polarizer. Parallel and crossed transmission and reflection values were measured with the e-vector of the polarized light parallel or perpendicular, respectively, to the stretch direction of the film. All scans were continuous and were conducted with a scan rate of 480 nanometers per minute and a slit width of 2 nanometers. Reflection was performed in the "V-reflection"

20 mode. Transmission and reflectance values are averages of all wavelengths from 400 to 700 nanometers.

Transmission electron micrographs were taken of finished film, cross-sectioned in a plan perpendicular to the machine direction to determine the nature of the dispersed phase. The outer layers of three-layer constructions were removed

25 from oriented film, leaving only the blend layer for embedding. Samples were embedded in 3M Scotchcast™ 5 Electrical Resin which was cured at room temperature. The embedded samples were microtomed using a diamond knife, on a Reichert Ultracut™ S microtome at room temperature, into thin sections of approximately 90nm thickness, using a cutting rate of 0.2 millimeters per second.

30 The thin sections were floated onto distilled, deionized water and collected for transmission electron microscopic evaluation on a 200 mesh copper grid reinforced

with a carbon/formvor substrate. Photomicrographs were taken using a JEOL 200CX Transmission Electron Microscope.

Scanning electron microscopic evaluations were performed on cast webs prior to film orientation to determine the nature of the disperse phase. Pieces of web were fractured to expose a plane perpendicular to the machine direction while immersed in liquid nitrogen. Samples were then trimmed and mounted on aluminum stubs prior to sputter coating with gold palladium. Photomicrographs were taken using a Hitachi S530 Scanning Electron Microscope.

EXAMPLE 1

In Example 1, an optical film was made in accordance with the invention by extruding a blend of 75% polyethylene naphthalate (PEN) as the continuous or major phase and 25% of polymethylmethacrylate (PMMA) as the disperse or minor phase into a cast film or sheet about 380 microns thick using conventional extrusion and casting techniques. The PEN had an intrinsic viscosity (IV) of 0.52 (measured in 60% phenol, 40% dichlorobenzene). The PMMA was obtained from ICI Americas, Inc., Wilmington, Delaware, under the product designation CP82. The extruder used was a 3.15 cm (1.24") Brabender with a 1 tube 60 μm Tegra filter. The die was a 30.4 cm (12") EDI Ultraflex™ 40.

About 24 hours after the film was extruded, the cast film was oriented in the width or transverse direction (TD) on a polyester film tentering device. The stretching was accomplished at about 9.1 meters per minute (30 ft/min) with an output width of about 140 cm (55 inches) and a stretching temperature of about 160°C (320°F). The total reflectivity of the stretched sample was measured with an integrating sphere attachment on a Lambda 19 spectrophotometer with the sample beam polarized with a Glan-Thompson cube polarizer. The sample had a 75% parallel reflectivity (i.e., reflectivity was measured with the stretch direction of the film parallel to the e-vector of the polarized light), and 52% crossed reflectivity (i.e., reflectivity was measured with the e-vector of the polarized light perpendicular to the stretch direction).

EXAMPLE 2

In Example 2, an optical film was made and evaluated in a manner similar to Example 1 except using a blend of 75% PEN, 25% syndiotactic polystyrene (sPS), 0.2% of a polystyrene glycidyl methacrylate compatibilizer, and 0.25% each

5   of Irganox™ 1010 and Ultranox™ 626. The synthesis of polystyrene glycidyl methacrylate is described in Polymer Processes, "Chemical Technology of Plastics, Resins, Rubbers, Adhesives and Fibers", Vol. 10, Chap. 3, pp. 69-109 (1956)(Ed. by Calvin E. Schildknecht).

The PEN had an intrinsic viscosity of 0.52 measured in 60% phenol, 40%

10   dichlorobenzene. The sPS was obtained from Dow Chemical Co. and had a weight average molecular weight of about 200,000, designated subsequently as sPS-200-0. The parallel reflectivity on the stretched film sample was determined to be 73.3%, and the crossed reflectivity was determined to be 35%.

15   EXAMPLE 3

In Example 3, an optical film was made and evaluated in a manner similar to Example 2 except the compatibilizer level was raised to 0.6%. The resulting parallel reflectivity was determined to be 81% and the crossed reflectivity was determined to be 35.6%.

20

EXAMPLE 4

In Example 4, an three layer optical film was made in accordance with the present invention utilizing conventional three layer coextrusion techniques. The film had a core layer and a skin layer on each side of the core layer. The core layer

25   consisted of a blend of 75% PEN and 25% sPS 200-4 (the designation sPS-200-4 refers to a copolymer of syndiotactic-polystyrene containing 4 mole % of para-methyl styrene), and each skin layer consisted of 100% PEN having an intrinsic viscosity of 0.56 measured in 60% phenol, 40% dichlorobenzene.

The resulting three-layer cast film had a core layer thickness of about 415

30   microns, and each skin layer was about 110 microns thick for a total thickness of about 635 microns. A laboratory batch stretcher was used to stretch the resulting

three-layer cast film about 6 to 1 in the machine direction (MD) at a temperature of about 129°C. Because the edges of the film sample parallel to the stretch direction were not gripped by the lab stretcher, the sample was unconstrained in the transverse direction (TD) and the sample necked-down in the TD about 50% as a result of the stretch procedure.

Optical performance was evaluated in a manner similar to Example 1. The parallel reflectivity was determined to be 80.1%, and the crossed reflectivity was determined to be 15%. These results demonstrate that the film performs as a low absorbing, energy conserving system.

EXAMPLES 5-29

In Examples 5-29, a series of optical films were produced and evaluated in a manner similar to Example 4, except the sPS fraction in the core layer and the IV of the PEN resin used were varied as shown in Table 1. The IV of the PEN resin in the core layer and that in the skin layers was the same for a given sample. The total thickness of the cast sheet was about 625 microns with about two-thirds of this total in the core layer and the balance in the skin layers which were approximately equal in thickness. Various blends of PEN and sPS in the core layer were produced, as indicated in Table 1. The films were stretched to a stretch ratio of about 6:1 in either the machine direction (MD) or in the transverse direction (TD) at various temperatures as indicated in Table 1. Some of the samples were constrained (C) in the direction perpendicular to the stretch direction to prevent the sample from necking down during stretching. The samples labeled "U" in Table 1 were unconstrained and permitted to neckdown in the unconstrained dimension. Certain optical properties of the stretched samples, including percent transmission, reflection, and absorption, were measured along axes both parallel and crossed or perpendicular to the direction of stretch. The results are summarized in TABLE 1.

Heat setting, as indicated for Examples 24-27, was accomplished by manually constraining the two edges of the stretched sample which were perpendicular to the direction of stretch by clamping to an appropriately sized rigid frame and placing the clamped sample in an oven at the indicated temperature for 1

minute. The two sides of the sample parallel to the direction of stretch were
unconstrained (U) or not clamped and allowed to neckdown. The heatsetting of
Example 29 was similar except all four of the edges of the stretched sample were
constrained (C) or clamped. Example 28 was not heat set.

TABLE 1

Example Number	Stretch Temp. (°C)	Stretch Direction (MD/TD)	Stretch Constrained (C/U)	PEN IV	Fraction (sPS)	Heat Set Temp.	Constrained Heat Set	Trans. (Perp.)	Trans. (Para.)	Reflec. (Perp.)	Reflec. (Para.)
5	135	TD	C	0.53	0.25			76.2	20.4	22.6	75.3
6	135	TD	C	0.47	0.75			80.2	58.4	19.4	40
7	142	TD	C	0.53	0.25			74.2	21.8	25.3	77.3
8	142	TD	C	0.47	0.75			76.0	41.0	23.8	55.6
9	129	TD	C	0.53	0.25			71.2	21.2	26.5	76.2
10	129	TD	C	0.47	0.75			76.8	48.9	22.4	49.6
11	129	MD	U	0.53	0.25			81.5	27.6	17.2	67
12	129	TD	U	0.53	0.25			66.8	22.1	25	71.9
13	129	MD	U	0.47	0.25			79.5	20.3	19.3	73.7
14	129	TD	U	0.47	0.25			66.3	26.2	32.5	69.4
15	129	TD	U	0.47	0.5			73.0	26.2	24.7	68.7
16	129	MD	U	0.47	0.5			75.4	20.6	23.2	76.1
17	129	MD	U	0.47	0.1			82.1	27.3	16.9	67

Example Number	Stretch Temp. (°C)	Stretch Direction (MD/TD)	Stretch Constrained (C/U)	PEN IV	Fraction (sPS)	Heat Set Temp.	Constrained Heat Set	Trans. (Perp.)	Trans. (Para.)	Reflec. (Perp.)	Reflec. (Para.)
18	129	MD	U	0.56	0.25			80.1	15.0	18	80.3
19	129	TD	U	0.56	0.25			70.2	21.6	25.2	70.7
20	129	MD	C	0.47	0.25			75.8	28.7	23.4	70.1
21	129	MD	C	0.47	0.5			79.8	27.8	19.7	70.8
22	135	MD	C	0.47	0.1			80.5	36.7	19.2	62.6
23	135	MD	C	0.53	0.25			77.2	21.1	21.8	76.6
24	129	MD	U	0.56	0.25	150	U	83.7	17.3	17.3	74
25	129	MD	U	0.56	0.25	220	U	82.1	16	18	75.8
26	129	MD	U	0.56	0.25	135	U	84.7	17	18	75.3
27	129	MD	U	0.56	0.25	165	U	83	16	16.5	76.3
28	129	MD	U	0.56	0.25	CNTRL	C	83.7	17	17.5	76
29	129	MD	U	0.56	0.25	230	C				
29	129	MD	U	0.56	0.25	230	C				

All of the above samples were observed to contain varying shapes of the disperse phase depending on the location of the disperse phase within the body of the film sample. The disperse phase inclusions located nearer the surfaces of the samples were observed to be of an elongated shape rather than more nearly

5   spherical. The inclusions which are more nearly centered between the surfaces of the samples may be more nearly spherical. This is true even for the samples with the skin layers, but the magnitude of the effect is reduced with the skin layers. The addition of the skin layers improves the processing of the films by reducing the tendency for splitting during the stretching operation.

10   Without wishing to be bound by theory, the elongation of the inclusions (disperse phase) in the core layer of the cast film is thought to be the result of shear on the blend as it is transported through the die. This elongation feature may be altered by varying physical dimensions of the die, extrusion temperatures, flow rate of the extrudate, as well as chemical aspects of the continuous and disperse phase

15   materials which would alter their relative melt viscosities. Certain applications or uses may benefit from providing some elongation to the disperse phase during extrusion. For those applications which are subsequently stretched in the machine direction, starting with a disperse phase elongated during extrusion may allow a higher aspect ratio to be reached in the resulting disperse phase.

20   Another notable feature is the fact that a noticeable improvement in performance is observed when the same sample is stretched unconstrained. Thus, in Example 9, the % transmission was 79.5% and 20.3% in the parallel and perpendicular directions, respectively. By contrast, the transmission in Example 16 was only 75.8% and 28.7% in the parallel and perpendicular directions,

25   respectively. There is a thickness increase relative to constrained stretching when samples are stretched unconstrained, but since both transmission and extinction improve, the index match is probably being improved.

An alternative way to provide refractive index control is to modify the chemistry of the materials. For example, a copolymer of 30 wt % of

30   interpolymerized units derived from terephthalic acid and 70 wt % of units derived from 2,6-naphthalic acid has a refractive index 0.02 units lower than a 100% PEN

polymer. Other monomers or ratios may have slightly different results. This type of change may be used to more closely match the refractive indices in one axis while only causing a slight reduction in the axis which desires a large difference. In other words, the benefits attained by more closely matching the index values in one axis more than compensate for the reduction in an orthogonal axis in which a large difference is desired. Secondly, a chemical change may be desirable to alter the temperature range in which stretching occurs. A copolymer of sPS and varying ratios of para methyl styrene monomer will alter the optimum stretch-temperature range. A combination of these techniques may be necessary to most effectively optimize the total system for processing and resulting refractive index matches and differences. Thus, an improved control of the final performance may be attained by optimizing the process and chemistry in terms of stretching conditions and further adjusting the chemistry of the materials to maximize the difference in refractive index in at least one axis and minimizing the difference at least one orthogonal axis.

These samples displayed better optical performance if oriented in the MD rather than TD direction (compare Examples 14-15). Without wishing to be bound by theory, it is believed that different geometry inclusions are developed with an MD orientation than with a TD orientation and that these inclusions have higher aspect ratios, making non-ideal end effects less important. The non-ideal end effects refers to the complex geometry/index of refraction relationship at the tip of each end of the elongated particles. The interior or non-end of the particles are thought to have a uniform geometry and refractive index which is thought to be desirable. Thus, the higher the percentage of the elongated particle that is uniform, the better the optical performance.

The extinction ratio of these materials is the ratio of the transmission for polarizations perpendicular to the stretch direction to that parallel to the stretch direction. For the examples cited in Table 1, the extinction ratio ranges between about 2 and about 5, although extinction ratios up to 7 have been observed in optical bodies made in accordance with the present invention without any attempt to optimize the extinction ratio. It is expected that even higher extinction ratios

-78-

(e.g., greater than 100) can be achieved by adjusting film thickness, inclusion volume fraction, particle size, and the degree of index match and mismatch, or through the use of iodine or other dyes.

5   EXAMPLES 30-100

In Examples 30-100, samples of the invention were made using various materials as listed in Table 2. PEN 42, PEN 47, PEN 53, PEN 56, and PEN 60 refer to polyethylene naphthalate having an intrinsic viscosity (IV) of 0.42, 0.47, 0.53, 0.56, and 0.60, respectively, measured in 60% phenol, 40% dichlorobenzene.

10   The particular sPS-200-4 used was obtained from Dow Chemical Co. Ecdel™ 9967 and Eastar™ are copolyesters which are available commercially from Eastman Chemical Co., Rochester, New York. Surlyn™ 1706 is an ionomer resin available from E.I. du Pont de Nemours & Co., Wilmington, Delaware. The materials listed as Additive 1 or 2 include polystyrene glycidyl methacrylate. The

15   designations GMAPS2, GMAPS5, and GMAPS8 refer to glycidyl methacrylate having 2, 5, and 8% by weight, respectively, of glycidyl methacrylate in the total copolymer. ETPB refers to the crosslinking agent ethyltriphenylphosphonium bromide. PMMA VO44 refers to a polymethylmethacrylate available commercially from Atohaas North America, Inc.

20   The optical film samples were produced in a manner similar to Example 4 except for the differences noted in Table 2 and discussed below. The continuous phase and its ratio of the total is reported as major phase. The disperse phase and its ratio of the total is reported as minor phase. The value reported for blend thickness represents the approximate thickness of the core layer in microns. The

25   thickness of the skin layers varied when the core layer thickness varied, but was kept to a constant ratio, i.e., the skin layers were approximately equal and the total of the two skin layers was about one-third of the total thickness. The size of the disperse phase was determined for some samples by either scanning electron microscope (SEM) or transmission electron microscope (TEM). Those examples

30   which were subsequently stretched using the laboratory batch orienter are shown by an "X" in the column labeled Batch Stretched.

TABLE 2

Example Number	Major Phase	Major Phase (%)	Minor Phase	Minor Phase (%)	Core Layer (microns)	Additive 1	Additive 2	SEMs	TEM (microns)	Batch Stretched
30	PEN.42	75	sPS-200-4	25	9.8	-	-	-	-	-
31	PEN.42	75	sPS-200-4	25	16.3	-	-	10	-	-
32	PEN.47	75	sPS-200-4	25	9.8	-	-	-	-	x
33	PEN.47	75	sPS-200-4	25	16.3	-	-	8	-	x
34	PEN.47	50	sPS-200-4	50	9.8	-	-	-	-	-
35	PEN.47	50	sPS-200-4	50	16.3	-	-	5	-	x
36	PEN.47	90	sPS-200-4	10	9.8	-	-	-	-	-
37	PEN.47	90	sPS-200-4	10	16.3	-	-	3	-	x
38	PEN.53	75	sPS-200-4	25	9.8	-	-	-	-	-
39	PEN.53	75	sPS-200-4	25	16.3	-	-	7	-	x
40	PEN.56	75	sPS-200-4	25	9.8	-	-	-	-	-
41	PEN.56	75	sPS-200-4	25	16.3	-	-	6	-	x
42	sPS-200-4	75	PEN.42	25	9.8	-	-	-	-	-

Example Number	Major Phase	Major Phase (%)	Minor Phase	Minor Phase (%)	Core Layer (microns)	Additive 1	Additive 2	SEMs	TEM (microns)	Batch Stretched
43	sPS-200-4	75	PEN.42	25	16.3	.	.	.	.	.
44	sPS-200-4	75	PEN.47	25	9.8	.	.	.	.	.
45	sPS-200-4	75	PEN.47	25	16.3	.	.	.	.	x
46	sPS-200-4	75	PEN.53	25	16.3	.	.	.	.	.
47	sPS-200-4	75	PEN.53	25	9.8	.	.	.	.	.
48	sPS-200-4	75	PEN.56	25	9.8	.	.	.	.	.
49	sPS-200-4	75	PEN.56	25	16.3	.	.	.	.	.
50	PET.60	75	Ecdel ™ 9967	25	16.3	.	.	.	.	.

Example Number	Major Phase	Major Phase (%)	Minor Phase	Minor Phase (%)	Core Layer (microns)	Additive 1	Additive 2	SEMs	TEM (microns)	Batch Stretched
51	PET.60	75	Surlyn™ 1706	25	16.3	-	-	2	-	-
52	PEN.47	75	Ecdel™ 9967	25	16.3	-	-	2	-	x
53	PEN.47	100	-	-	16.3	-	-	-	-	-
54	PEN.47	75	sPS-200	25	16.3	-	-	-	-	-
55	PEN.47	75	sPS-200	25	9.8	-	-	10	-	-
56	PEN.47	75	sPS-320	25	9.8	-	-	12	-	-
57	PEN.47	75	sPS-320	25	16.3	-	-	-	-	-
58	PEN.47	95	sPS-320	5	9.8	-	-	-	-	-
59	PEN.47	95	sPS-320	5	16.3	-	-	-	-	-
60	PEN.56	100	-	-	16.3, 9.8	-	-	-	-	x
61	PEN.56	75	sPS-200	25	9.8	-	-	10	-	-
62	PEN.56	75	sPS-200	25	16.3	-	-	-	-	x
63	PEN.56	95	sPS-200	5	9.8	-	-	-	-	-
64	PEN.56	95	sPS-200	5	16.3	-	-	-	-	x
65	PEN.56	75	sPS-320	25	9.8	-	-	10	-	-

Example Number	Major Phase	Major Phase (%)	Minor Phase	Minor Phase (%)	Core Layer (microns)	Additive 1	Additive 2	SEMs	TEM (microns)	Batch Stretched
66	PEN.56	75	sPS-320	25	16.3	-	-	-	-	-
67	PEN.47	95	sPS-200	5	16.3	2% GMAPS2	0.25% ETPB	1	0.3	x
68	PEN.47	95	sPS-200	5	9.8	2% GMAPS2	0.25% ETPB	-	-	-
69	PEN.56	75	sPS-200	25	9.8	6% GMAPS2	0.25% ETPB	-	-	-
70	PEN.56	75	sPS-200	25	16.3	6% GMAPS2	0.25% ETPB	0.5	2.5	x
71	PEN.56	75	sPS-200	25	9.8	2% GMAPS2	0.25% ETPB	-	0.8	-
72	PEN.56	75	sPS-200	25	16.3	2% GMAPS2	0.25% ETPB	1	-	-
73	PEN.56	95	sPS-200	5	9.8	2% GMAPS2	0.25% ETPB	-	-	-
74	PEN.56	95	sPS-200	5	16.3	2% GMAPS2	0.25% ETPB	-	-	-

Example Number	Major Phase	Major Phase (%)	Minor Phase	Minor Phase (%)	Core Layer (microns)	Additive 1	Additive 2	SEMs	TEM (microns)	Batch Stretched
75	PEN.56	75	sPS-200	25	9.8	6% GMAPS2	0.25% ETPB	-	-	-
76	PEN.56	75	sPS-200	25	16.3	6% GMAPS2	0.25% ETPB	0.8	1	x
77	PEN.56	75	sPS-200	25	9.8	2% GMAPS2	0.25% ETPB	-	-	-
78	PEN.56	75	sPS-200	25	16.3	2% GMAPS2	0.25% ETPB	-	-	-
79	PEN.56	75	sPS-200	25	9.8	6% GMAPS2	0.25% ETPB	-	-	-
80	PEN.56	75	sPS-200	25	16.3	6% GMAPS2	0.25% ETPB	-	-	x
81	PEN.56	75	sPS-200	25	9.8	6% GMAPS2	0.25% ETPB	-	-	-
82	PEN.56	75	sPS-200	25	16.3	6% GMAPS2	0.25% ETPB	0.5	-	-

Example Number	Major Phase	Major Phase (%)	Minor Phase	Minor Phase (%)	Core Layer (microns)	Additive 1	Additive 2	SEMs	TEM (microns)	Batch Stretched
83	PEN.56	95	sPS-200	5	9.8	2% GMAPS2	0.25% ETPB	-	-	-
84	PEN.56	95	sPS-200	5	16.3	2% GMAPS2	0.25% ETPB	-	-	-
85	PEN.56	75	sPS-200	25	9.8	0.5% GMAPS2	0.25% ETPB	-	-	-
86	PEN.56	75	sPS-200	25	9.8	0.5% GMAPS2	0.25% ETPB	-	-	-
87	PEN.47	75	Eastar	25	16.3	-	-	-	-	x
88	PEN.47	75	Eastar	25	9.8	-	-	-	-	-
89	PEN.47	75	Eastar	25	16.3	-	-	-	-	-
90	PEN.47	75	Eastar	25	9.8	-	-	-	-	-
91	PEN.47	75	PMMA VO44	25	9.8	-	-	-	-	-
92	PEN.47	75	PMMA VO44	25	16.3	-	-	10	-	-

Example Number	Major Phase	Major Phase (%)	Minor Phase	Minor Phase (%)	Core Layer (microns)	Additive 1	Additive 2	SEMs	TEM (microns)	Batch Stretched
93	PEN.47	75	PMMA VO44	25	16.3	6% MMA/GMA	-	-	0.7	-
94	PEN.47	75	PMMA VO44	25	9.8	6% MMA/GMA	-	-	-	-
95	PEN.47	75	PMMA VO44	25	9.8	2% MMA/GMA	-	-	1.2	-
96	PEN.47	75	PMMA	25	16.3	2% MMA/GMA	-	-	-	x
97	PEN.47	75	sPS-200-4 VO44	25	916.3	0.5% Congo Red	-	-	-	x
98	PEN.47	75	sPS-200-4	25	16.3	0.15% Congo Red	-	-	-	x
99	PEN.47	75	sPS-200-4	25	9.8	0.25% Methylene Blue	-	-	-	-

Example Number	Major Phase	Major Phase (%)	Minor Phase	Minor Phase (%)	Core Layer (microns)	Additive 1	Additive 2	SEMs	TEM (microns)	Batch Stretched
100	PEN.47	75	sPS-200-4	25	9.8	0-0.25% Methylene Blue	-	-	-	-

The presence of the various compatibilizers was found to reduce the size of the included or disperse phase.

5   EXAMPLE 101

In Example 101, an optical film was made in a manner similar to Example 4 except the resulting core thickness was about 420 microns thick, and each skin layer was about 105 microns thick. The PEN had a 0.56 IV. The cast film was oriented as in Example 1, except the temperature of stretch was 165°C and there

10   was a 15 day delay between casting and stretching. The transmission was 87.1% and 39.7% for parallel and perpendicularly polarized light, respectively.

EXAMPLES 102 - 121

In Examples 102 - 121, optical films were made as in Example 101, except

15   that orientation conditions were varied and/or the sPS-200-0 was replaced with either copolymers of sPS containing either 4 or 8 mole % of para-methyl styrene or with an atactic-form of styrene, Styron 663 (available from Dow Chemical Company, Midland, Michigan) as listed in Table 3. Evaluations of transmission properties are also reported. Transmission values are averaged over all

20   wavelengths between 450-700 nm.

TABLE 3

Ex.	% sPS	PS	PEN IV	Temperature of Draw (°C)	Rail Setting (cm)	Perpendicular Transmission (%)	Parallel Transmission (%)
101	25	200-0	0.56	165	152	87.1	39.7
102	35	200-0	0.56	165	152	87.8	44.4
103	15	200-4	0.56	165	152	86.1	43.5
104	25	200-4	0.56	165	152	86.5	43.6
105	35	200-4	0.56	165	152	88.2	50.7
106	15	200-8	0.56	165	152	89.3	40.7
107	25	200-8	0.56	165	152	88.5	42.8
108	35	200-8	0.56	165	152	88.6	43.3
109	15	Styron 663	0.56	165	152	89.3	45.7
110	25	Styron 663	0.56	165	152	87.8	41.6
111	35	Styron 663	0.56	165	152	88.8	48.2
112	15	Styron 663	0.48	165	152	88.5	62.8
113	25	Styron 663	0.48	165	152	87.1	59.6
114	35	Styron 663	0.48	165	152	86.8	59.6
115	15	200-0	0.48	165	152	88.0	58.3
116	25	200-0	0.48	165	152	88.0	58.7
117	35	200-0	0.48	165	152	88.5	60.6
118	15	200-4	0.48	165	152	89.0	57.4
119	35	200-4	0.48	165	152	87.3	64.0
120	35	200-0	0.56	171	127	86.5	65.1

Ex.	% sPS	PS	PEN IV	Temperature of Draw (°C)	Rail Setting (cm)	Perpendicular Transmission (%)	Parallel Transmission (%)
121	35	200-0	0.56	171	152	88.1	61.5

These examples indicate that the particles of the included phase are elongated more in the machine direction in high IV PEN than in low IV PEN. This is consistent with the observation that, in low IV PEN, stretching occurs to a

5   greater extent near the surface of the film than at points interior to the film, with the result that fibrillar structures are formed near the surface and spherical structures are formed towards the center.

Some of these Examples suggest that the orientation temperatures and degree of orientation are important variables in achieving the desired effect.

10   Examples 109 to 114 suggest that quiescent crystallization need not be the only reason for the lack of transmission of a preferred polarization of light.

EXAMPLES 122-124

In Example 122, a multilayer optical film was made in accordance with the

15   invention by means of a 209 layer feedblock. The feedblock was fed with two materials: (1) PEN at 38.6 kg per hour (intrinsic viscosity of 0.48); and (2) a blend of 95% coPEN and 5% by weight of sPS homopolymer (200,000 molecular weight). The coPEN was a copolymer based on 70 mole % naphthalene dicarboxylate and 30 mole % dimethyl isophthalate polymerized with ethylene

20   glycol to an intrinsic viscosity of 0.59. The coPEN/sPS blend was fed into the feedblock at a rate of 34.1 kg per hour.

The coPEN blend material was on the outside of the extrudate, and the layer composition of the resulting stack of layers alternated between the two materials. The thicknesses of the layers was designed to result in a one-quarter

25   wavelength stack with a linear gradient of thicknesses, and having a 1.3 ratio from the thinnest to the thickest layer. Then, a thicker skin layer of coPEN (made in accordance with the method described above to make the coPEN/sPS blend, except

the molar ratios were 70/15/15 naphthalene dicarboxylate /dimethyl
terephthalate/dimethyl isophthalate) devoid of sPS was added to each side of the
209 layer composite. The total skin layer was added at a rate of 29.5 kg per hour,
with about one-half of this quantity on each side or surface of the stack.

5   The resulting skin layer clad multilayer composite was extruded through a
multiplier to achieve a multilayer composite of 421 layers. The resulting
multilayer composite was then clad with another skin layer of the 70/15/15 coPEN
on each surface at a total rate of 29.5 kg per hour with about one-half of this
quantity on each side. Since this second skin layer may not be separately

10   detectable from the existing skin layer (as the material is the same), for the
purposes of this discussion, the resulting extra thick skin layer will be counted as
only one layer.

       The resulting 421 layer composite was again extruded through a 1.40 ratio
asymmetric multiplier to achieve a 841 layer film which was then cast into a sheet

15   by extruding through a die and quenching into a sheet about 30 mils thick. The
resulting cast sheet was then oriented in the width direction using a conventional
film making tentering device. The sheet was stretched at a temperature of about
300°F (149°C) to a stretch ratio of about 6:1 and at a stretch rate of about 20% per
second. The resulting stretched film was about 5 mils thick.

20   In Example 123, a multilayer optical film was made as in Example 122,
except that the amount of sPS in the coPEN/sPS blend was 20% instead of 5%.

       In Example 124, a multilayer optical film was made as in Example 122,
except that no sPS was added to the film.

       The results reported in Table 4 include a measure of the optical gain of the

25   film. The optical gain of a film is the ratio of light transmitted through an LCD
panel from a backlight with the film inserted between the two to the light
transmitted without the film in place. The significance of optical gain in the context
of optical films is described in WO 95/17692 in relation to Figure 2 of that
reference. A higher gain value is generally desirable. The transmission values

30   include values obtained when the light source was polarized parallel to the stretch
direction ($T_{\parallel}$) and light polarized perpendicular to the stretch direction ($T_{\perp}$). Off-

angle-color (OAC) was measured using an Oriel spectrophotometer as the root mean square deviation of p-polarized transmission at 50 degree incident light of wavelength between 400 and 700 nm.

5   TABLE 4

Ex.	mole % sPS	Gain	$T_\perp$ (%)	$T_\parallel$ (%)	OAC (%)
122	5	1.5	83	2	1.5
123	20	1.45	81	1.5	1.2
124	0	1.6	87	5	3.5

The value of off-angle-color (OAC) demonstrates the advantage of using a multilayer construction within the context of the present invention. In particular,

10   such a construction can be used to substantially reduce OAC with only a modest reduction in gain. This tradeoff may have advantages in some applications. The values of $T_\parallel$ for the examples of the invention may be lower than expected because light scattered by the sPS dispersed phase may not be received by the detector.

15   EXAMPLE 125

A three layer film was made in accordance with Example 4. The core layer consisted of 70% coPEN whose intrinsic viscosity was 0.55 measured in 60% phenol, 40% dichlorobenzene, 70% sPS 200-7, plus an additional 2% Dylark 332-80 (available from NOVA Chemical). Each skin consisted of 100% coPET having

20   an intrinsic viscosity of 0.65 measured in methylene chloride.

The coPEN was a copolymer based on 62 mole % naphthalene dicarboxylate and 38 mole % dimethyl terephthalate. The coPET was a copolymer based on 80 mole % dimethyl carboxylate and 20 mole % dimethyl isophthalate.

The cast film was oriented in a manner consistent with Example 1. The

25   stretching was accomplished at 5.8 meters per minute (19 feet per minute) with an output width of 147 cm (58 inches). The stretch temperature was 124°C. The heat set temperature was 163°C. The perpendicular transmission was 85.3%, and the parallel transmission was 21.7%.

EXAMPLES 126 - 130

The following examples illustrate the production of a co-continuous morphology in an optical system of the present invention.

5   In Examples 126 through 130, a series of optical films were produced and evaluated in a manner similar to Example 125, except the sPS fraction in the core layer and the stretch temperature were varied as shown in Table 5.

TABLE 5

Example Number	Fraction sPS	Dispersed or Co-continuous	Stretch Temperature (°C)	Trans. (Perp.)	Trans. (Para.)
125	0.30	D	124	85.3	21.7
126	0.35	D	135	86.3	21.1
127	0.40	D	129	86.4	21.9
128	0.44	--	124	85.8	25.9
129	0.53	C	129	86.6	33.6
130	0.81	D	135	88.1	69

10

The parallel and perpendicular transmission values for Examples 125 to 130 show good optical performance. The high value for perpendicular transmission for Example 130 transmission suggests an effective match in the refractive indices in both phases for polarized light aligned in the direction

15   perpendicular to the stretch direction.

Scanning electron micrographs were taken of fracture surfaces of cast web for Examples 126 and 127. As in Example 125, there was clear evidence of spherical or elliptical particles dispersed in an otherwise continuous matrix. Transmission electron micrographs were taken for Examples 129 and 130; these

20   are shown in Figs. 6a and 6b, respectively. Fig. 6a illustrates the morphology of co-continuous phases. Inspection of the micrograph shows inclusions of both the coPEN and the sPS phases, as well as regions where each appears to be the continuous phase. By contrast, Fig. 6b shows coPEN dispersed into an sPS matrix.

EXAMPLE 131

A three layer film was made in accordance with Example 4. The core layer consisted of 85% coPEN whose instrinsic viscosity was 0.51 measured in a solution of 60% phenol and 40% dichlorobenzene, and 15% 250k-7, plus an additional 2% Dylark™ 332-80. Each skin consisted of 100% coPEN.

The coPEN used as part of the core was a copolymer based on 70 mole % naphthalene dicarboxylate and 30 mole % dimethyl terephthalate. The coPEN used in the skin layers was a copolymer based on 70 mole % naphthalene dicarboxylate and 30 mole % dimethyl isophthalate.

The cast film was oriented in a manner consistent with Example 1. The stretching was accomplished at 5.3 meters per minute (17.4 feet per minute) with an output width of 124.5 cm (49 inches). The stretch temperature was 118°C. The heat set temperature was 141°C. The perpendicular transmission was 81.9%, and the parallel transmission was 32.7%. The perpendicular transmission spectrum is presented in Figure 7.

EXAMPLE 132

A film with an antireflection layer was prepared by first adding 10 grams of Remet™ SP-30 (Remet Coporation, Chadwicks, NY) with 1 gram Tritox™ X-100 (Rohm and Haas, Philadelphia, PA) into 89 grams of deionized water. The solution was coated onto a piece of film from Example 131 utilizing a #3 wire wound rod to yield a dry coating thickness of approximately 200 nanometers. The perpendicular transmission was 83.8%, and the parallel transmission was 33.3%.

EXAMPLE 133

Example 131 was repeated, except that both sides of the film were coated with an antireflection layer. The perpendicular transmission was 86.2%, and the parallel transmission was 33.8%.

The perpendicular transmission spectra for Examples 131-133 are presented in Fig. 7. One can see from Fig. 7 that the overall slope of the perpendicular

transmission as a function of wavelength is lower for Examples 132-133 relative to Example 131, particularly for the range of wavelength from. One skilled in the art will appreciate that a film exhibiting a flat transmission curve as a function of the wavelength of light will minimize any changes in color to a resultant display

5   device into which the reflective polarizer might be incorporated.

EXAMPLES 134 - 135

These examples illustrates the use of the films of the present invention as high efficiency light extractors for light guiding structures.

10   In Example 134, an optical film was made in accordance with the present invention by extruding a composition consisting of 30% sPS in a matrix of 70/30/0 coPEN. The extruded film was oriented in the machine direction to a stretch ratio of 2.5:1.

In Example 135, a second film was made from the same composition as

15   Example 134 and using a similar procedure. However, instead of orienting the film in the machine direction, the film was oriented uniaxially in the direction transverse to the machine direction using a tenter stretch of 4.8:1.

The films of Examples 134 and 135 were mechanically fastened as cladding to separate optical fibers, using a silica grease to eliminate the fiber-air interface.

20   The experimental set-up is depicted schematically in FIG. 8. The fibers were then connected to a 60 watt xenon metal halide short arc lamp obtained from General Electric Company, Danbury, CT. The optical fibers had a thickness of 1.2 cm and consisted of a low Tg acrylic polymer.

When the lamp was turned on, the two samples became illuminated and

25   produced diffusely scattered light. When the two film samples were viewed through a polarizing film at an orientation perpendicular to one plane of polarization, both samples appeared substantially darkened. However, when the polarizing film was rotated 90° in the same plane, both samples appeared diffusely bright, indicating that the transmission of light through the films was polarization

30   specific.

The effect of capping the ends of the fibers was also investigated. When the ends were reflectively capped so that a portion of the light escaping from the ends of the fibers was reflected back into the fibers, the intensity of light produced by the films increased. This is consistent with the creation of a light cavity in which light of the non-extracted polarization undergoes further reflections within the optical fiber until it is converted, by degrees, into the extracted polarization. With the light within the fiber being unable to exit the fiber except through the extractor, the extraction efficiency increased. In addition, polarization conversion of the light interacting with the fiber/air interface caused a greater portion of light to be extracted from the fiber in the desired polarization.

EXAMPLE 136

The following example illustrates the increase in gain achievable at non-normal incident angles with the optical films of the present invention.

A three layer film was made in accordance with Example 4. The core layer consisted of 70% PEN whose instrinsic viscosity was 0.48 (measured in 60% phenol, 40% dichlorobenzene) and 30% sPS 200-8. Each skin consisted of 100% coPEN and comprised about 17% of the total thickness of the cast film.

The coPEN was a copolymer of 70 mole % naphthalene dicarboxylate and 30 mole % dimethyl isophthalate. The viscosity of the coPEN was not measured.

The cast film was oriented in a manner consistent with Example 1. The stretching was accomplished at 5.5 meters per minute (18 feet per minute) with an output width of 141 cm (55.5 inches). The stretch temperature was 154°C. The heat set temperature was 164°C. The resultant film was 128 micrometers thick.

A Sharp C12P backlight was placed against the one face of a standard dichroic polarizer. The intensity of the light radiating from the backlight/polarizer assembly was measured using a Photo research PR650 Spectra Colorimeter. The backlight/polarizer assembly is oriented relative to the detector of the PR650 prior to the start of the measurement such that the plane containing the arc swept by the detector arm also contains the axis of high transmission for the polarizer. The detector arm is swept plus and minus 60 degrees about a direction perpendicular to

the backlight/polarizer assembly. A second intensity measurement was made with piece of film 23 cm square placed between the backlight and the polarizer such that the perpendicular transmission axis of the film was coincident with the high transmission direction of the polarizer. The ratio of the two intensities for each

5   angular position with the optical film in place to that without is reported as the Relative Gain.

The data for Example 136 is shown in Figure 9A. The average relative gain at the angles plus and minus 60 degrees from the normal was 1.45. This data demonstrates that the relative gain for the film of Example 136 increases at non-

10   normal incident angles, particularly for angles from 30° to 60° away from normal incidence.

COMPARATIVE EXAMPLE 1

The following example illustrates the decrease in gain at non-normal

15   incident angles for a typical commercially available optical film.

A piece of microreplicated brightness enhancement film from Sekisui W518 (Osaka, Japan) was measured using the Eldim 120D as described in Example 136. The ratio of the intensities for each angular position with the Sekisui W518 film in place to that without the Sekisui film is shown as Figure 9B.

20   The average relative gain at the angles plus and minus 60 degrees from the normal was 0.65, indicating that the gain for the film peaks at normal incidence and declines for all angles away from normal incidence.

As demonstrated by Example 136 and Comparative Example 1, films can be made in accordance with the present invention in which the relative gain

25   increases at non-normal incident angles, particularly for angles from 30° to 60° away from normal incidence. By contrast, the relative gain for commercially available optical films typically peaks at normal incidence and declines for all angles away from normal incidence. This feature of the films of the present invention make them particularly advantageous for use in applications such as

30   brightness enhancement films for large displays, where one will likely view the display across a wide range of angles.

EXAMPLES 137 - 150

The following examples further illustrate the increase in gain at non-normal angles of incidence achieved with the films of the present invention.

5   A series of examples were made in a manner similar to Example 136, except that material and process changes were made as indicated. In some of the examples, Irganox™ 1425 antioxidant (available from Ciba Geigy) and/or Dylark™ 332-80 (available from NOVA Chemicals) were added. The average relative gain for the angles plus and minus 60 degrees from the normal as well as the relative

10   gain at normal incidence (0 degrees) are reported in Table 6.

TABLE 6

Ex.	sPS	% Irganox 1425	% Dylark	Stretch Temp.	Heat Set Temp.	Relative Gain (0°)	Relative Gain (+/- 60°)
137	30%, 200-8	0	0	160	164	1.18	1.40
138	30%, 200-8	0	0	154	199	1.21	1.48
139	30%, 200-8	0.5	2	154	199	1.20	1.46
140	30%, 200-8	0	2	154	199	1.18	1.47
141	15%, 200-8	0.5	0	154	199	1.15	1.48
142	15%, 200-8	0.5	0	154	199	1.21	1.47
143	30%, 200-4	0	0	154	199	1.16	1.47
144	30%, 200-4	0.5	0	154	199	1.29	1.47
145	30%, 290-8	0.5	0	154	199	1.06	1.35
146	30%, 290-8	0.5	2	154	199	1.13	1.43
147	30%, 200-8	0.5	2	154	164	1.21	1.47
148	30%, 200-8	0	2	154	164	1.17	1.47
149	15%, 200-8	0.5	0	154	164	1.21	1.47
150	30%, 200-4	0	0	154	164	1.23	1.38

The preceding description of the present invention is merely illustrative, and is not intended to be limiting. Therefore, the scope of the present invention should be construed solely by reference to the appended claims.

5

(

WHAT IS CLAIMED IS:

1.   A direction control polarizer which provides directional and polarization control of light incident upon it, comprising:

5   a polarizer adapted to specularly transmit light having a first polarization orientation and to diffusely reflect light having a different polarization orientation; and

               a first light directing material adapted to transmit light within a desired angular zone, and to reflect light which would not exit the first light directing

10   material within the desired angular zone;

               wherein the polarizer and the first light directing material operate together to control direction and polarization of light transmitted by the direction control polarizer.

15   2.   The direction control polarizer of claim 1 wherein the polarizer comprises an optical device, comprising:

               a polymeric first phase and a second phase, disposed within said first phase, said second phase being discontinuous along at least two of any three mutually perpendicular axes; wherein said first and second phases have indices of refraction

20   which differ along a first axis by more than about 0.05, and which differ along a second axis orthogonal to said first axis by less than about 0.05.

3.   The direction control polarizer of claim 1 wherein the light directing material is positioned to receive the light of the first polarization orientation

25   transmitted by the polarizer.

4.   The direction control polarizer of claim 1 wherein the polarizer is positioned to receive the light in the output wedge transmitted by the light directing material.

30

5.   The direction control polarizer of claim 1 wherein the first light directing material comprises a structured surface material.

6.   The direction control polarizer of claim 5 wherein the first light directing material has a smooth side and a structured side.

7.   The direction control polarizer of claim 6 wherein the structured side comprises a plurality of triangular prisms.

8.   The direction control polarizer of claim 7 wherein the structured side comprises an array of triangular prisms.

9.   The direction control polarizer of claim 8 wherein the array of triangular prisms defines an axis of orientation.

10.   The direction control polarizer of claim 9 wherein the axis of orientation of the first light directing material is aligned with the orientation direction of the polarizer.

11.   The direction control polarizer of claim 7 wherein the triangular prisms are isosceles triangular prisms.

12.   The direction control polarizer of claim 7 wherein the triangular prisms have included angles in the range of 60 degrees to 120 degrees.

13.   The direction control polarizer of claim 12 wherein the triangular prisms have included angles in the range of 70 degrees to 110 degrees.

14.   The direction control polarizer of claim 13 wherein the triangular prisms have included angles in the range of 85 degrees to 95 degrees.

15.   The direction control polarizer of claim 14 wherein the triangular prisms have included angles of about 90 degrees.

16.   The direction control polarizer of claim 6 wherein the structured side comprises a plurality of structures having rounded peaks.

17.   The direction control polarizer of claim 16 wherein the structured side comprises a plurality of structures having rounded valleys.

18.   The direction control polarizer of claim 12 wherein the smooth side of the first light directing material is positioned toward the polarizer.

19.   The direction control polarizer of claim 18 wherein the structured side of the first light directing material is positioned toward the polarizer.

20.   The direction control polarizer of claim 1 wherein there is an air gap between the polarizer and the first light directing material.

21.   The direction control polarizer of claim 1 wherein the polarizer and the first light directing material form a unitary structure.

22.   The direction control polarizer of claim 1 further including a second light directing material.

23.   The direction control polarizer of claim 22 wherein the second light directing material is adapted such that light entering the second light directing material within a third preselected group of angles to the axis is reflected and light entering the second light directing material within a fourth predetermined group of angles to the axis is refracted such that a majority of the light in the fourth group of angles forms an output wedge that is narrower than its associated input wedge, the

angles in the fourth group of angles being greater than the angles in the third group of angles.

24.   The direction control polarizer of claim 22 wherein the second light directing material comprises a structured surface material.

25.   The direction control polarizer of claim 24 wherein the second light directing material includes a smooth side and a structured side.

26.   The direction control polarizer of claim 25 wherein the structured side of the second light directing material includes a plurality of triangular prisms.

27.   The direction control polarizer of claim 26 wherein the structured side of the second light directing material includes an array of triangular prisms, wherein the array defines an associated axis of orientation.

28.   The direction control polarizer of claim 27 wherein the axis of orientation of the first light directing material is positioned with respect to the axis of orientation of the second light directing material to provide two dimensional angular control of light transmitted by the first and second light directing materials.

29.   The direction control polarizer of claim 28 wherein the axis of orientation of the first light directing material is positionend at an angle greater than 0 degrees with respect to the axis of orientation of the second strucutred surface material.

30.   The direction control polarizer of claim 29 wherein the triangular prisms have included angles in the range of 60 degrees to 120 degrees.

31.   The direction control polarizer of claim 30 wherein the triangular prisms have included angles in the range of 70 degrees to 110 degrees.

32.   The direction control polarizer of claim 31 wherein the triangular prisms have included angles in the range of 85 degrees to 95 degrees.

33.   The direction control polarizer of claim 32 wherein the triangular prisms have included angles of about 90 degrees.

34.   The direction control polarizer of claim 28 wherein the structured side of the first light directing material is positioned toward the smooth side of the second light directing material.

35.   The direction control polarizer of claim 34 wherein the smooth side of the first light directing material is positioned toward a first side of the polarizer.

36.   The direction control polarizer of claim 35 wherein light is incident on a second side of the polarizer.

37.   The direction control polarizer of claim 36 wherein the structured side of the second light directing material is positioned toward the polarizer.

38.   The direction control polarizer of claim 37 wherein light is incident on the smooth side of the first light directing material.

39.   The direction control polarizer of claim 28 wherein the polarizer is positioned between the first and second light directing materials.

40.   The direction control polarizer of claim 39 wherein the first light directing material is positioned on a first side of the polarizer such that its smooth side is toward the polarizer, and further wherein the second light directing material is positioned on a second side of the polarizer such that its structured side is toward the polarizer.

41.   The direction control polarizer of claim 40 wherein light is incident on the smooth side of the second surface material.

42.   A direction control polarizer comprising:

5   a polarizer adapted to specularly transmit light having a first polarization orientation and to diffusely reflect light having a different polarization orientation, wherein the polarizer comprises an optical device, comprising:

a polymeric first phase and a second phase, disposed within said first phase, said second phase being discontinuous along at least two of any three mutually

10   perpendicular axes; wherein said first and second phases have indices of refraction which differ along a first axis by more than about 0.05, and which differ along a second axis orthogonal to said first axis by less than about 0.05; and

a light directing material positioned such that the light of the first polarization transmitted by the polarizer is incident on the smooth side, the light

15   directing material adapted to reflect light incident within a first input wedge, and to redirect light incident within a second input wedge into an output wedge that is narrower than the second input wedge, wherein the first input wedge is narrower than the second input wedge, and further wherein the first input wedge, second input wedge and output wedge are defined relative to an axis perpendicular to the first light

20   directing material;

wherein the light directing material includes a smooth side and a structured side comprised of an array of triangular prisms, the array defining an axis of orientation of the light directing material, the axis of orientation of the strucutred surface material is aligned with an orientation direction of the polarizer, and further

25   wherein the polarizer and the light directing material operate together to control direction and polarization of light transmitted by the direction control polarizer.

43.   A light control film providing polarization and two dimensional directional control of light, comprising:

30   a first light directing material adapted to reflect light incident within a first input wedge, and to redirect light incident within a second input wedge into a

first output wedge that is narrower than the second input wedge, wherein the first input wedge is narrower than the second input wedge, and further wherein the first input wedge, second input wedge and output wedge are defined relative to an axis perpendicular to the first light directing material, the first light directing material

5   including a smooth side and a structured side, the structured side including an array of triangular prisms which define an axis of orientation;

a second light directing material, positioned to receive light in the first output wedge, and adapted to reflect light incident within a third input wedge, and to redirect light incident within a fourth input wedge into a second output wedge that is

10   narrower than the fourth input wedge, wherein the third input wedge is narrower than the fourth input wedge, and further wherein the third input wedge, fourth input wedge and second output wedge are defined relative to an axis perpendicular to the second light directing material, the second light directing material including a smooth side and a structured side, the structured side including an array of triangular prisms

15   which define an axis of orientation;

wherein the axis of orientation of the second light directing material is orientated at an angle greater than 0 degrees with respect to the axis of orientation of the first light directing material; and

a polarizer adapted to specularly transmit light having a first

20   polarization orientation and to diffusely reflect light having a different polarization orientation, wherein the polarizer comprises an optical device, comprising:

a polymeric first phase and a second phase, disposed within said first phase, said second phase being discontinuous along at least two of any three mutually perpendicular axes;wherein said first and second phases have indices of refraction

25   which differ along a first axis by more than about 0.05, and which differ along a second axis orthogonal to said first axis by less than about 0.05;

wherein the polarizer, the first light directing material, and the second strucutred surface material provide polarization and two dimensional directional control of light transmitted by the direction control polarizer.

30

44.   A display comprising:

a display module;

lighting means for illuminating the display module, and for altering polarization orientation of light incident upon a surface within the light means; and

a polarizer positioned between the display module and the lighting

5   means, the polarizer adapted to transmit light from the lighting means having a first polarization orientation toward the display module, and to reflect light having a different polarization orientation toward the lighting means;

wherein the polarizer comprises a polymeric first phase and a second phase, disposed within said first phase, said second phase being discontinuous along at

10   least two of any three mutually perpendicular axes;

wherein said first and second phases have indices of refraction which differ along a first axis by more than about 0.05, and which differ along a second axis orthogonal to said first axis by less than about 0.05.

15   45.   The display of claim 44 wherein at least some of the light of the different polarization reflected toward the lighting means is converted to the first polarization orientation by the lighting means.

46.   The display of claim 45 wherein at least some of the converted light is

20   transmitted by the polarizer toward the display module.

47.   The display of claim 44 wherein the display further comprises a first light directing means for reflecting light incident within a first input wedge, and for redirecting light incident within a second input wedge into an output wedge that is

25   narrower than the second input wedge, wherein the first input wedge is narrower than the second input wedge, and further wherein the first input wedge, second input wedge and output wedge are defined relative to an axis perpendicular to the light directing material.

30   48.   The display of claim 47 wherein at least some the reflected light having the different polarization orientation is converted to the first polarization orientation by

the lighting means, and further wherein at least some of the light converted to the first polarization orientation is transmitted by the polarizer toward the display module.

5   49.   The display of claim 48 wherein the lighting means is further for converting direction of light incident upon a surface within the lighting means, herein at least some of the reflected light within the first input wedge is converted to light of the second input wedge by the lighting means, and further wherein at least some of the light converted to the second input wedge is directed by the first light directing

10   material toward the display module.

50.   The display of claim 47 wherein the light directing means comprises a structured surface material.

15   51.   The display of claim 50 wherein the first light directing material has a smooth side and a structured side.

52.   The display of claim 51 wherein the structured side is toward the liquid crystal module.

20

53.   The display of claim 51 wherein the structured side comprises a plurality of triangular prisms.

54.   The display of claim 53 wherein the plurality of triangular prisms define an

25   axis of orientation.

55.   The display of claim 54 wherein the axis of orientation of the first light directing material is aligned with the first in-plane direction of the polarizer.

30   56.   The display of claim 53 wherein the triangular prisms are isosceles triangular prisms.

57.   The display of claim 53 wherein the triangular prisms have included angles in the range of 70 degrees to 110 degrees.

5   58.   The display of claim 57 wherein the triangular prisms have included angles in the range of 80 degrees to 100 degrees.

59.   The display of claim 58 wherein the triangular prisms have included angles in the range of 85 degrees to 95 degrees.

10

60.   The display of claim 59 wherein the triangular prisms have included angles of about 90 degrees.

61.   The display of claim 47 wherein the light directing means is positioned
15   between the polarizer and the display module.

62.   The display of claim 47 wherein the first light directing material is positioned between the polarizer and the lighting means.

20   63.   The display of claim 62 wherein the structured side of the first light directing material is toward the liquid crystal module.

64.   The display of claim 47 further including a second light directing means for reflecting light incident within a third input wedge, and for redirecting light incident
25   within a fourth input wedge into a second output wedge that is narrower than the fourth input wedge, wherein the third input wedge is narrower than the fourth input wedge, and further wherein the third input wedge, fourth input wedge and second output wedge are defined relative to an axis perpendicular to the second light directing means.

30

65.   The display of claim 64 wherein the second light directing means further includes a smooth side and a structured side, wherein the structured side of the second light directing means defines an associated axis of orientation.

5   66.   The display of claim 65 wherein the axis of orientation of the first light directing means is positioned with respect to the axis of orientation of the second light directing means to provide two dimensional control of light transmitted by the first and second light directing means.

10   67.   The display of claim 66 wherein the axis of orientation of the first light directing means is at an angle greater than 0 degrees with respect to the axis of orientation of the second light directing means.

68.   The display of claim 67 wherein the angle is betweem 70-110degrees.

15

69.   The display of claim 68 wherein the angle is betweem 85-95 degrees.

70.   The display of claim 67 wherein the angle is about 90 degrees.

20   71.   The display of claim 66 wherein the structured side of the first light directing means is positioned toward the smooth side of the second light directing means.

72.   The display of claim 71 wherein the structured sides of both the first and
25   second light directing means are toward the liquid crystal module.

73.   The display of claim 66 wherein the first and second light directing means are positioned between the polarizer and the lighting means.

30   74.   The display of claim 73 wherein the first and second light directing means are positioned between the polarizer and the display module.

75.   The display of claim 74 wherein the first light directing means is positioned between the polarizer and the lighting means, and further wherein the second light directing means is positioned between the polarizer and the display module.

5

76.   A display, comprising:

a display module;

lighting means for illuminating the display module, for converting direction, and for converting polarization orientation of light incident upon a

10   surface within the lighting means and

a direction control polarizer, the direction control polarizer comprising:

a polarizer comprised of an optical device, comprising:

a polymeric first phase and a second phase, disposed within said first phase,

15   said second phase being discontinuous along at least two of any three mutually perpendicular axes; wherein said first and second phases have indices of refraction which differ along a first axis by more than about 0.05, and which differ along a second axis orthogonal to said first axis by less than about 0.05; and

a light directing material adapted to reflect light incident

20   within a first input wedge toward the lighting means, and to redirect light incident within a second input wedge into an output wedge that is narrower than the second input wedge toward the display module, wherein the first input wedge is narrower than the second input wedge, and further wherein the first input wedge, second input wedge and output wedge are defined relative to an axis perpendicular to the first light

25   directing material;

wherein at least some light of the polarization reflected by the polarizer is converted to light of the polarization transmitted by the polarizer by the lighting means, and further wherein at least some light converted to light of the polarization transmitted by the polarizer is transmitted by the polarizer toward the

30   display module;

and further wherein at least some of the reflected light within the first input wedge is converted to the second input wedge by the lighting means, and further wherein at least some of the light converted to the second input wedge is directed by the light directing material toward the display module.

5

77.   A display, comprising:

a display module;

lighting means for illuminating the display module;

conversion means for converting polarization of light;;

10   a polarizer positioned between the lighting means and the display module, the polarizer comprised of an optical device, comprising:

a polymeric first phase and a second phase, disposed within said first phase, said second phase being discontinuous along at least two of any three mutually perpendicular axes; wherein said first and second phases have indices of refraction

15   which differ along a first axis by more than about 0.05, and which differ along a second axis orthogonal to said first axis by less than about 0.05, such that the polarizer specularly transmits light of a first polarization and diffusely reflects light of a different polarization toward the conversion means;

wherein the conversion means and the polarizer operate together to provide

20   recycling of the light of the different polarization.

FIG. 1

FIG. 2
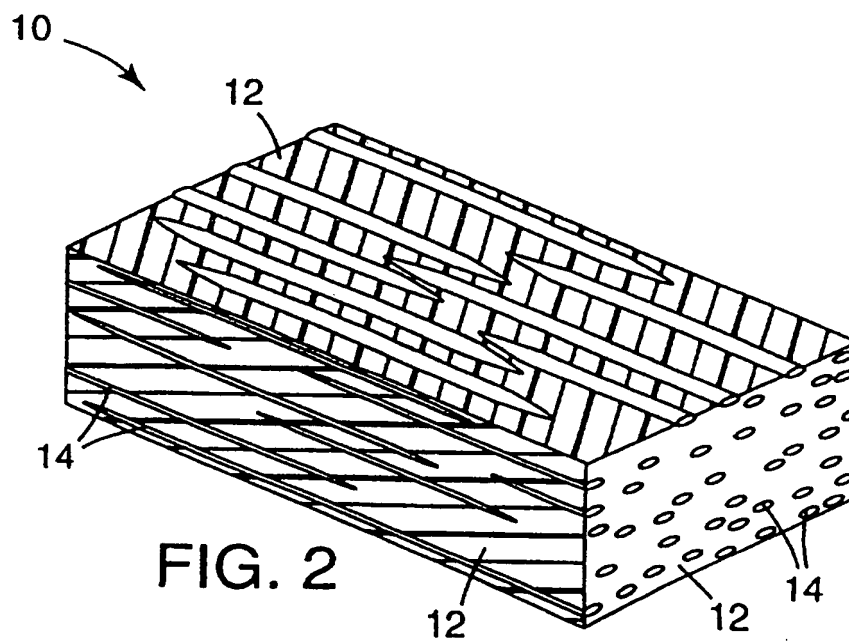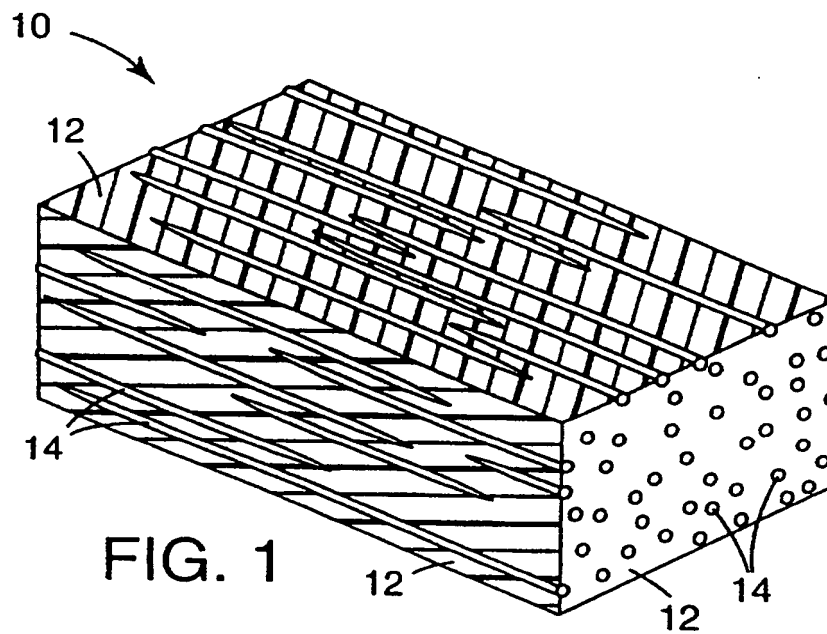
ORIENTATION
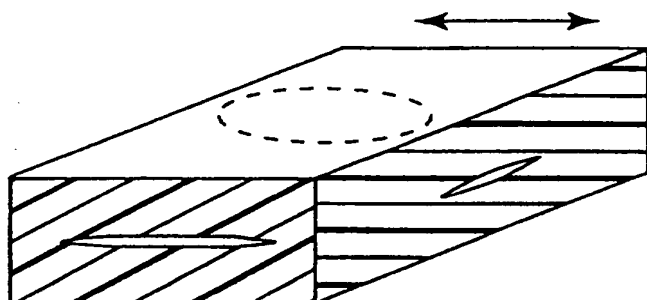
FIG. 3a
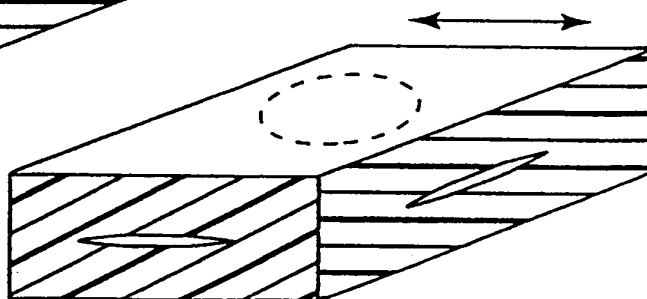
FIG. 3b
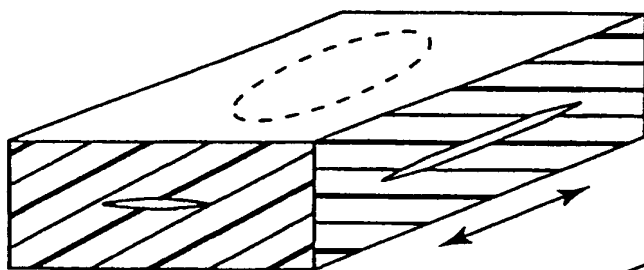
FIG. 3c
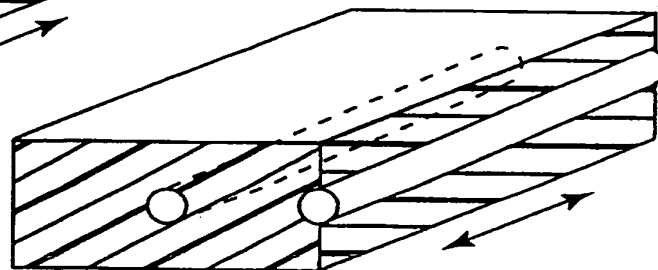
FIG. 3d
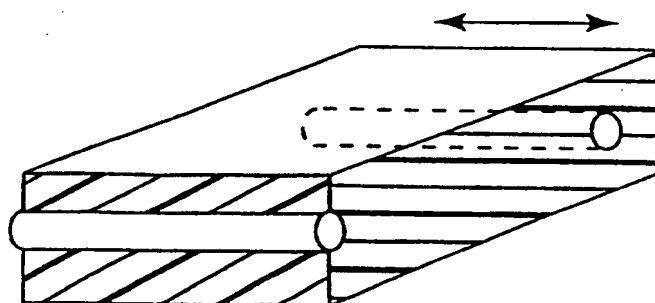
FIG. 3e
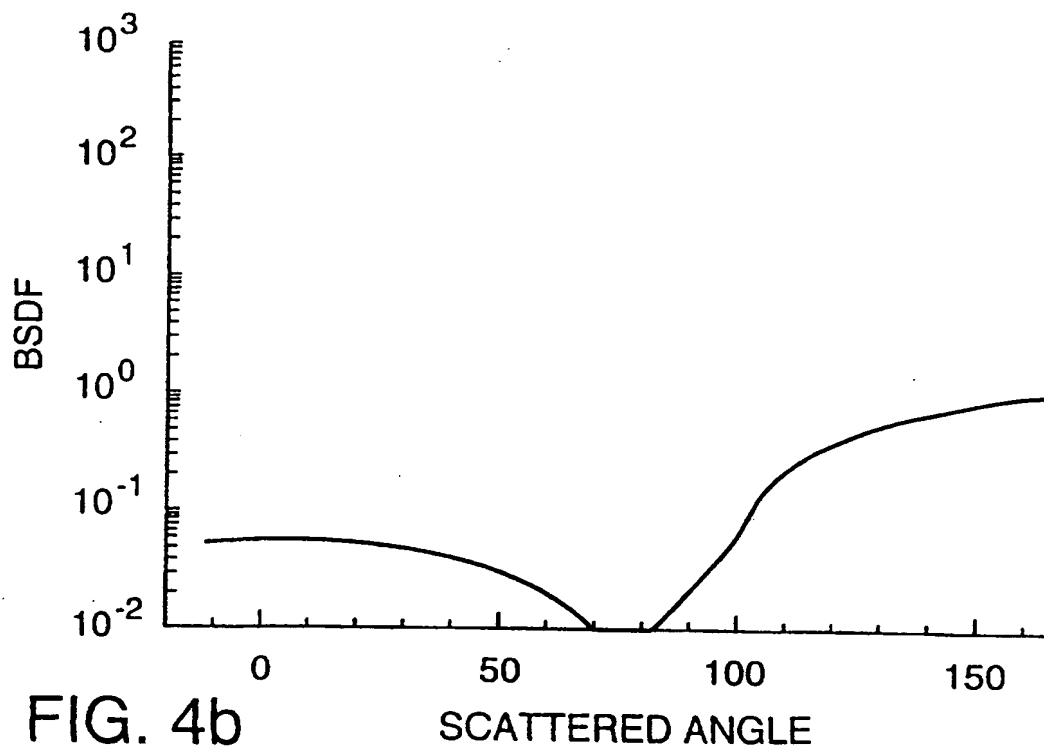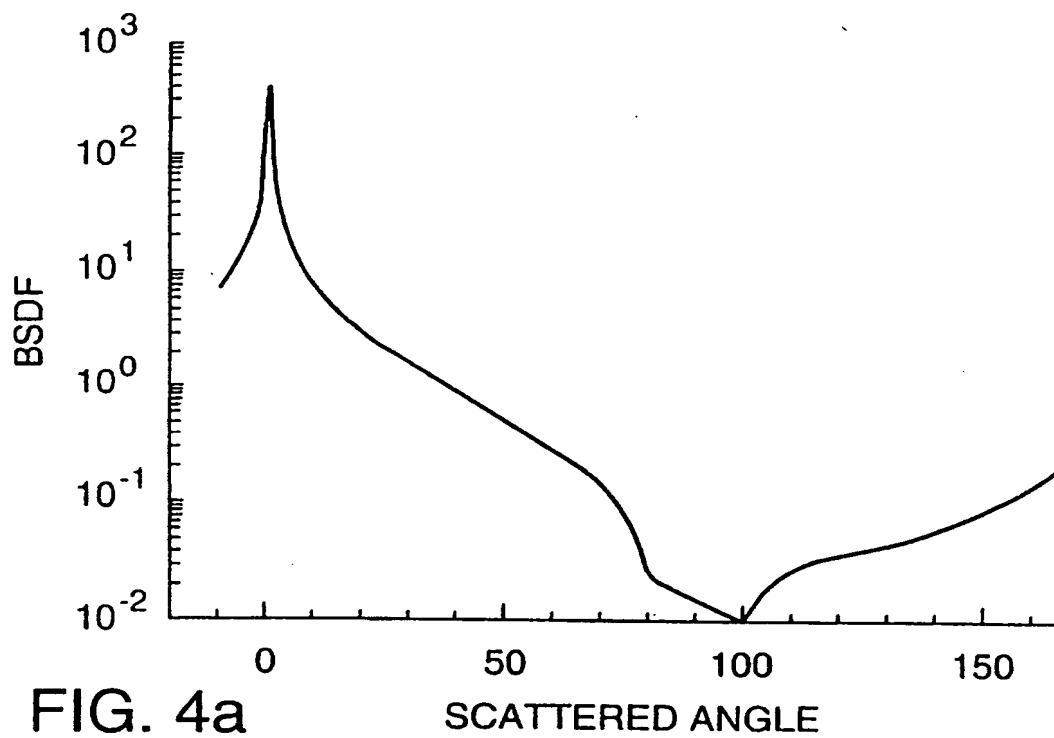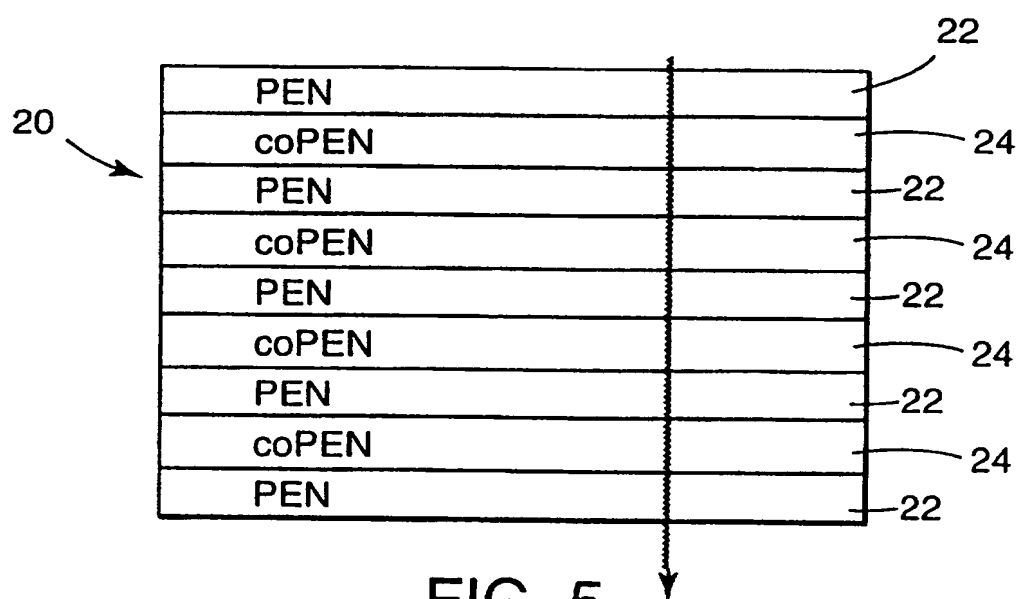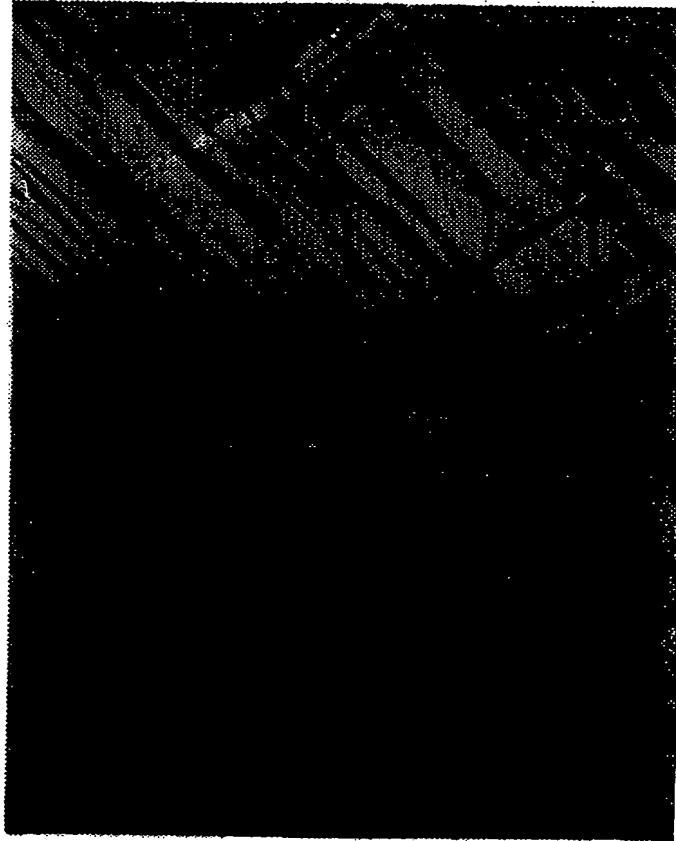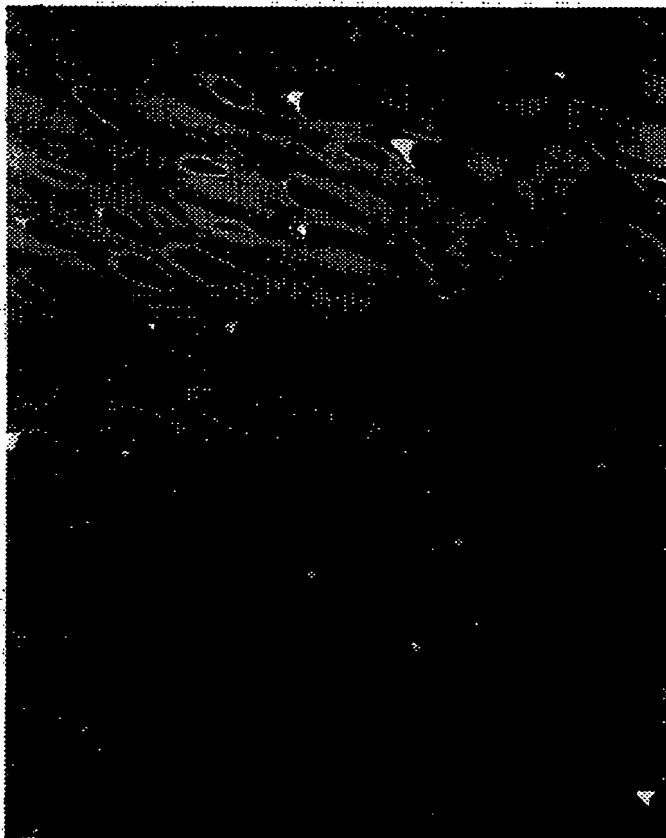
FIG. 4a   SCATTERED ANGLE
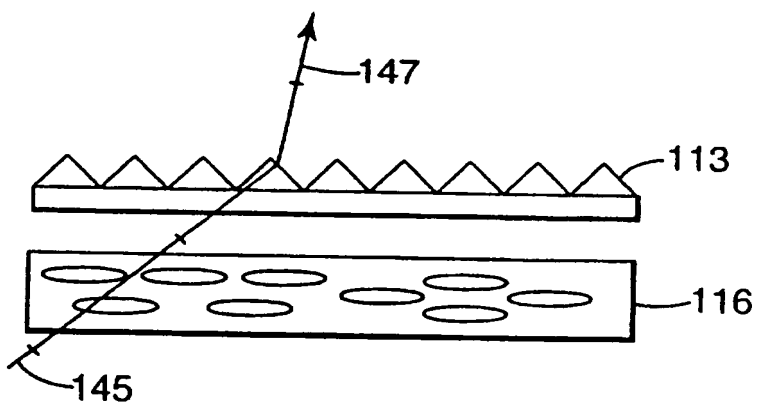

FIG. 4b   SCATTERED ANGLE

FIG. 5

FIG.6A

FIG.6B
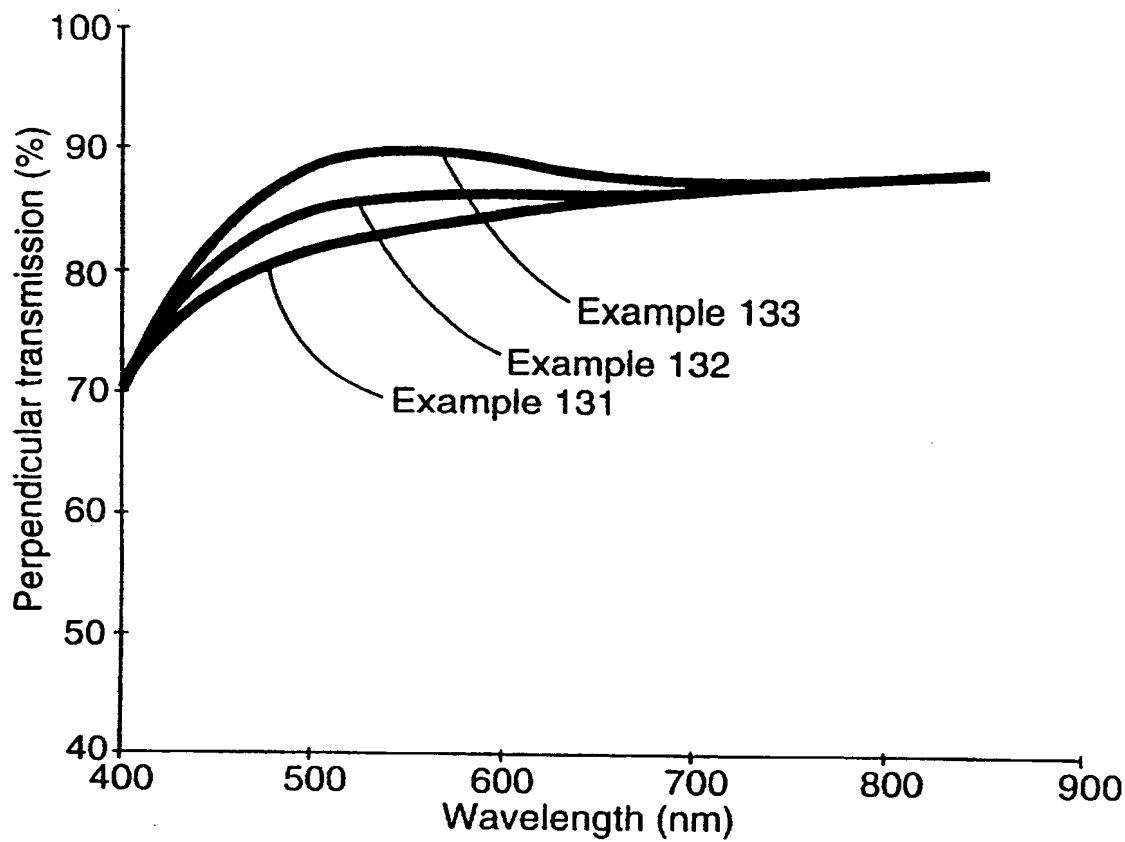
FIG. 7
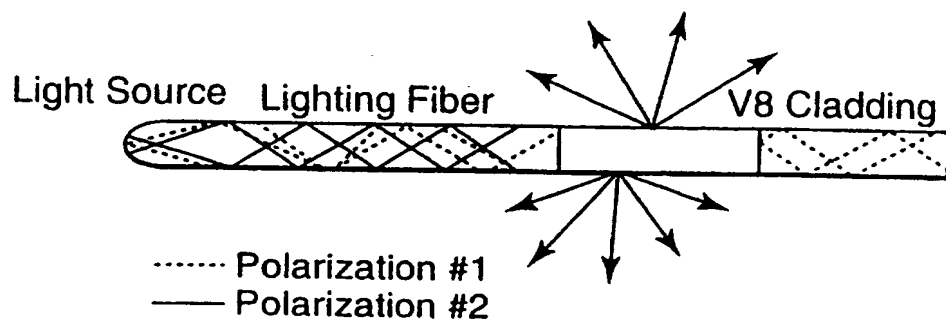
FIG. 8
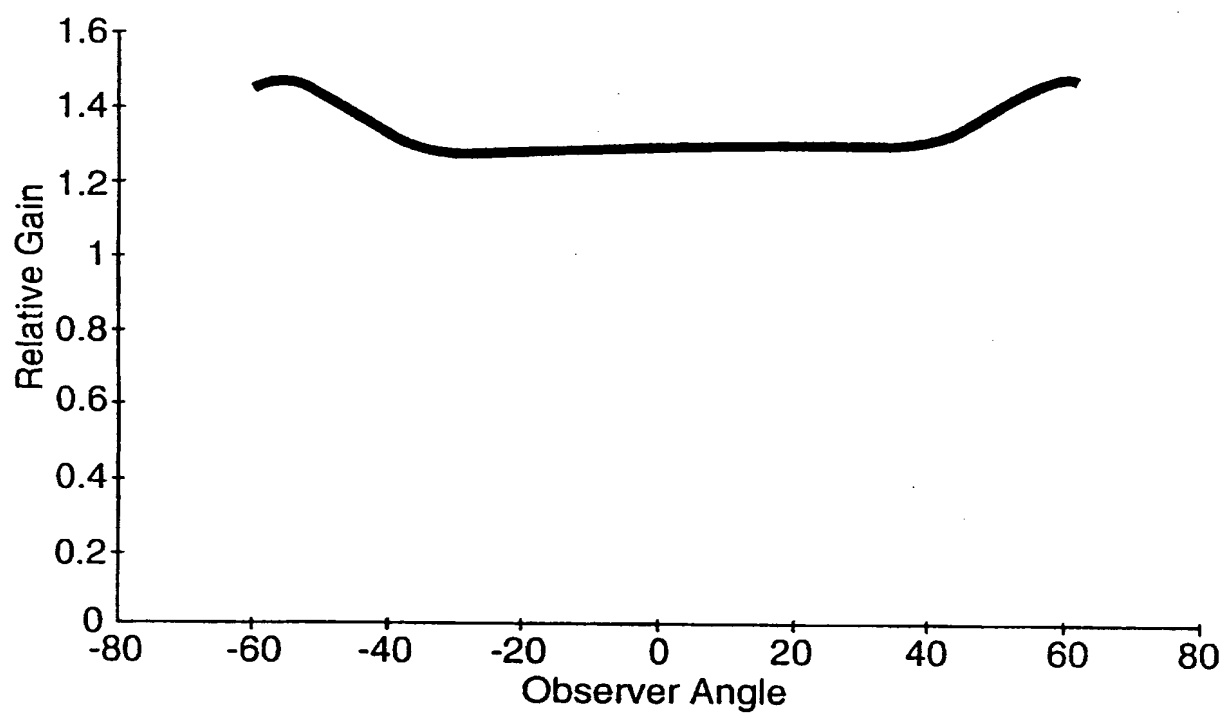
FIG. 9A
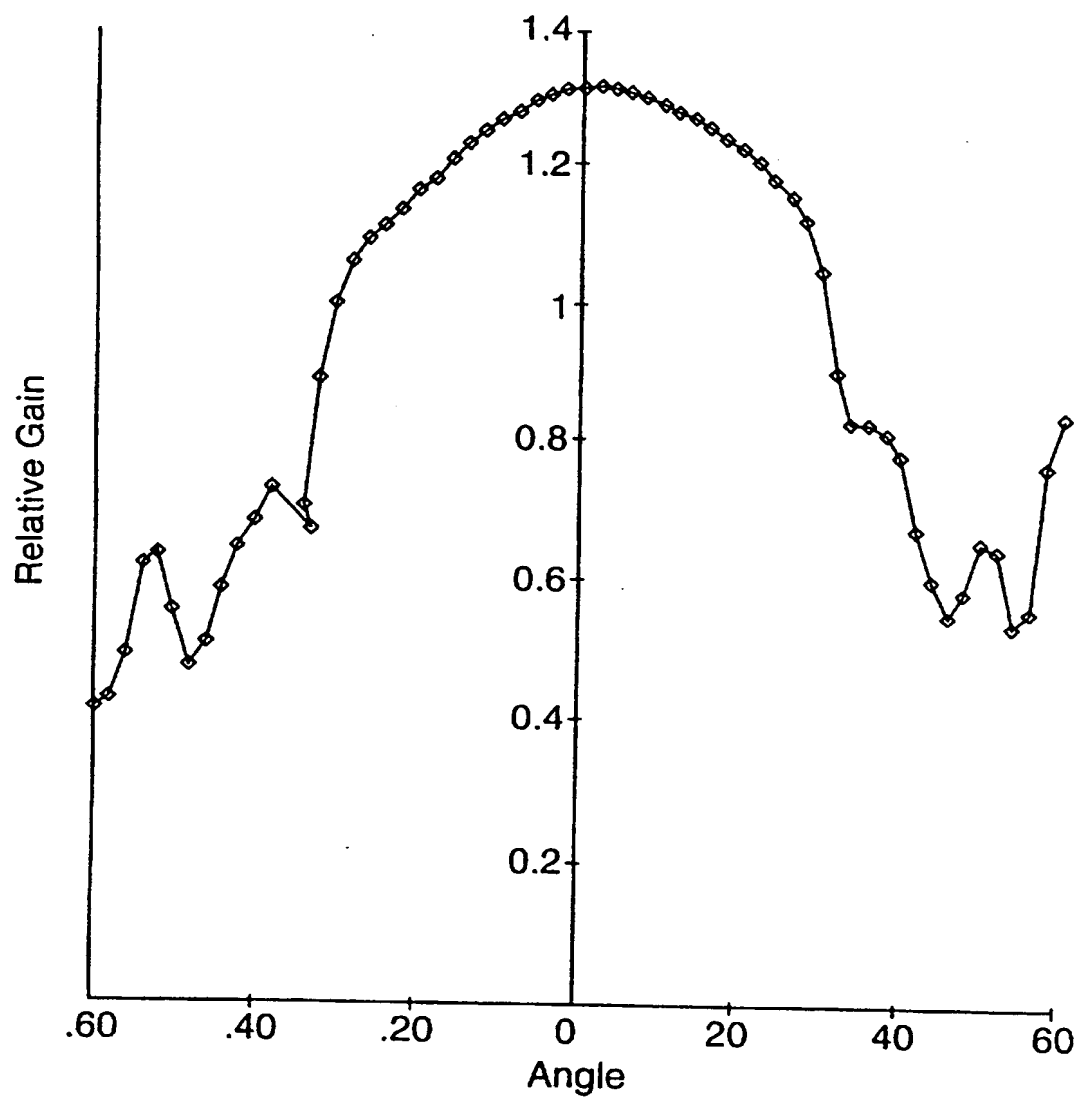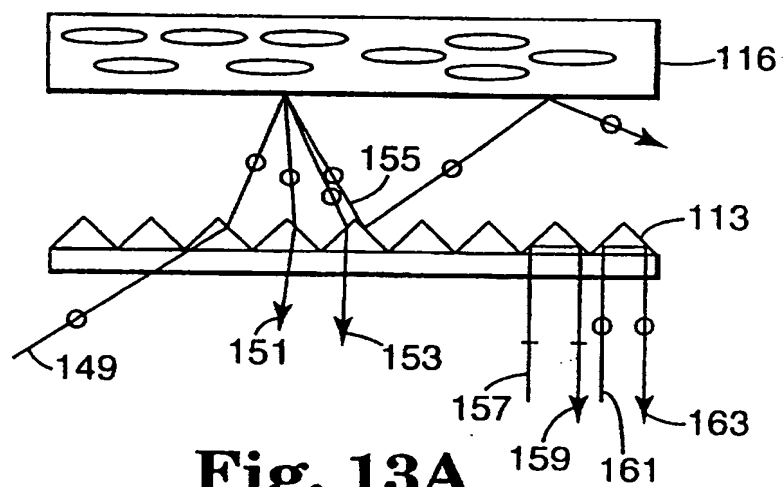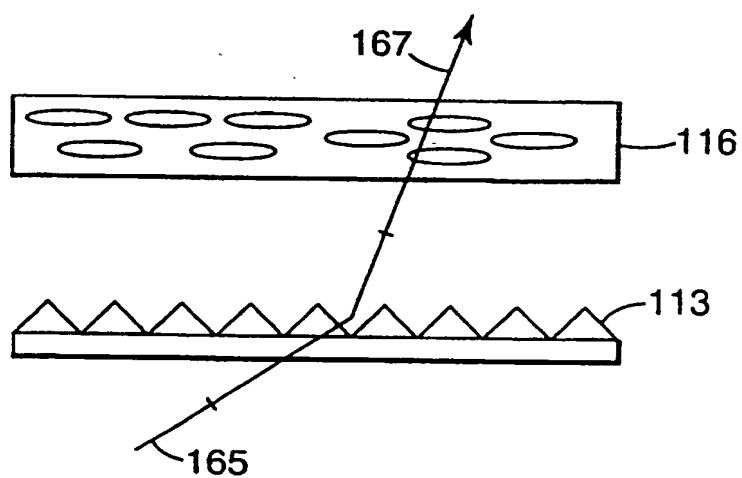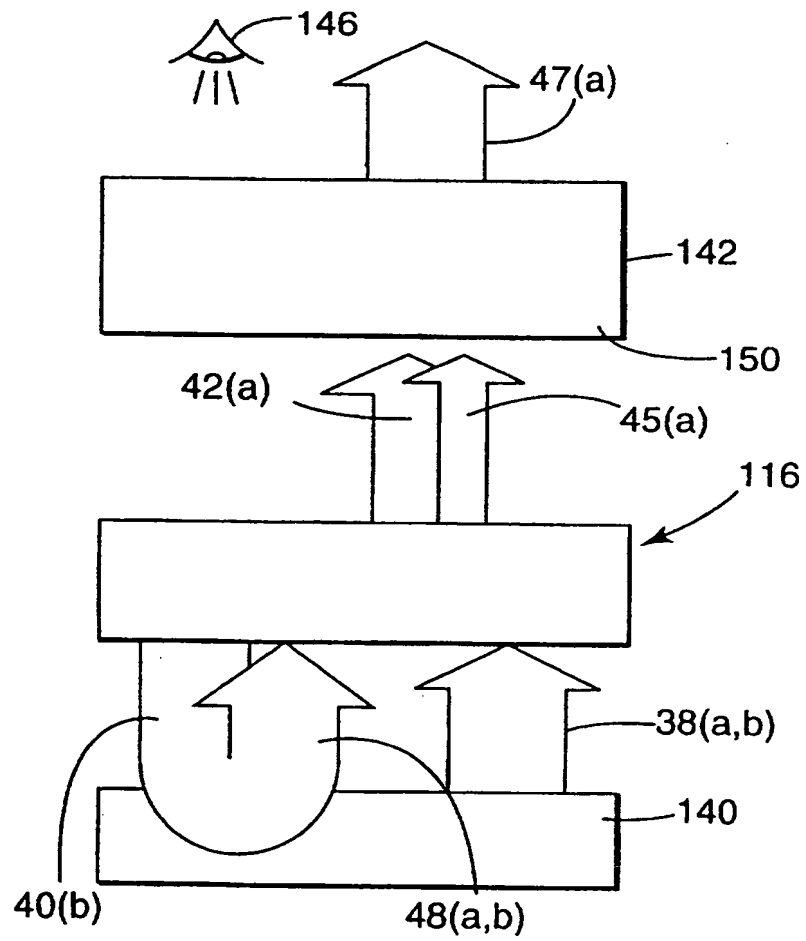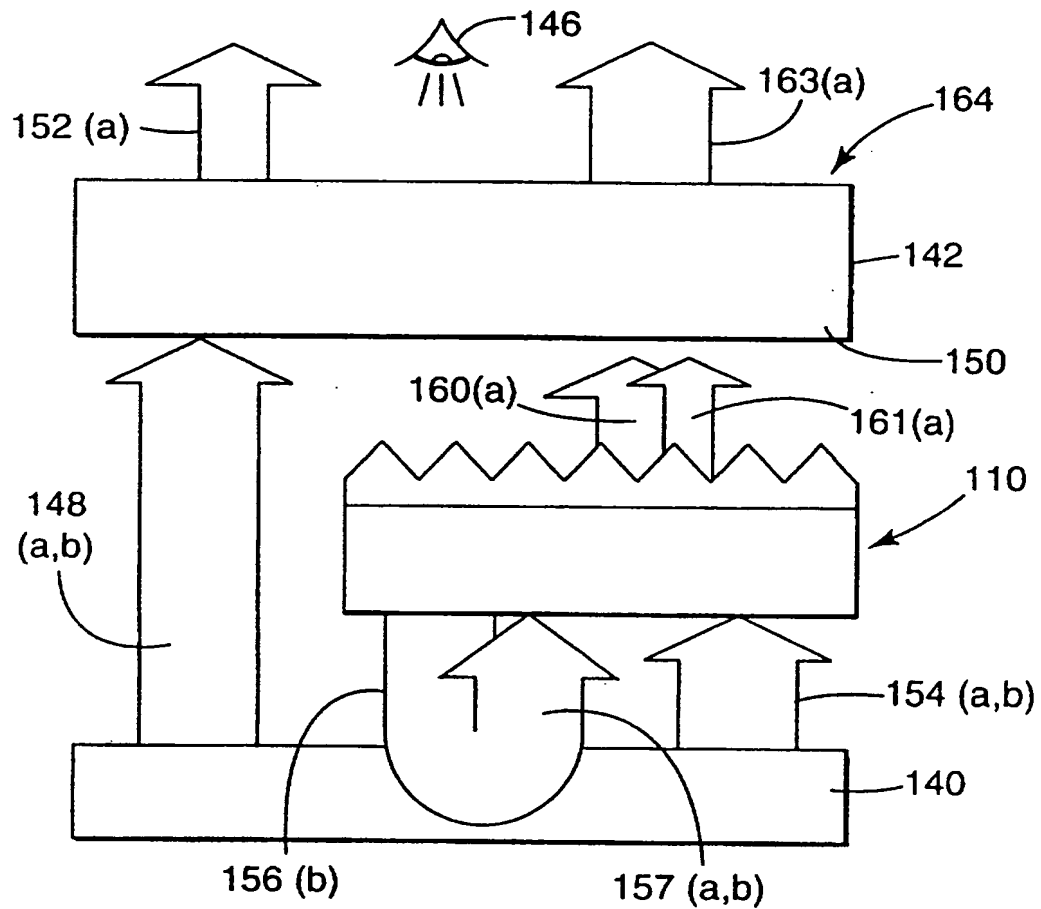
FIG. 9B
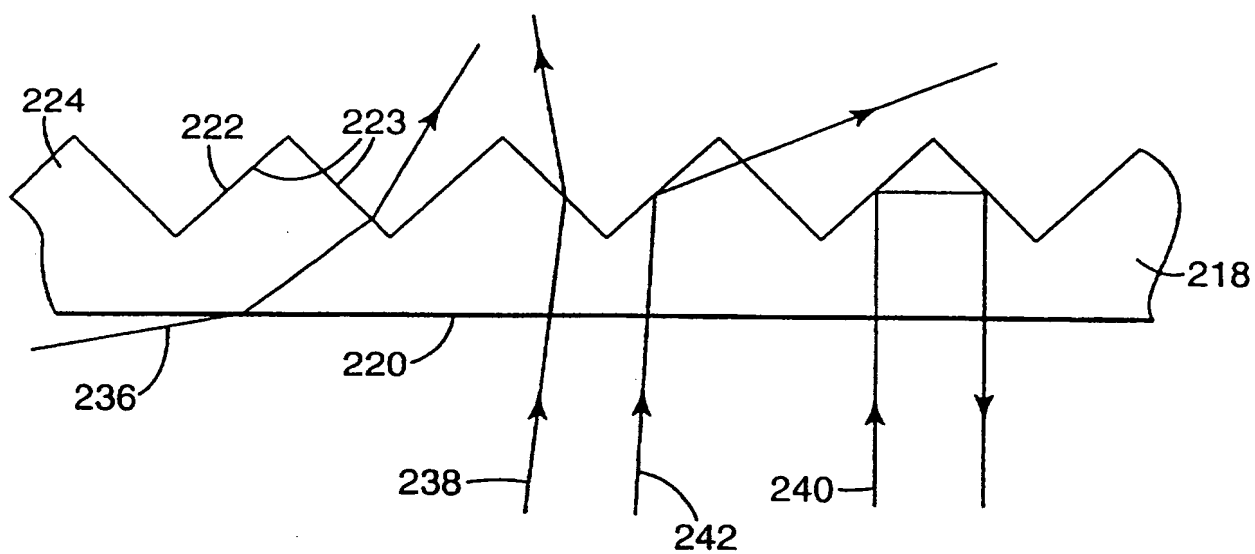
Fig. 10
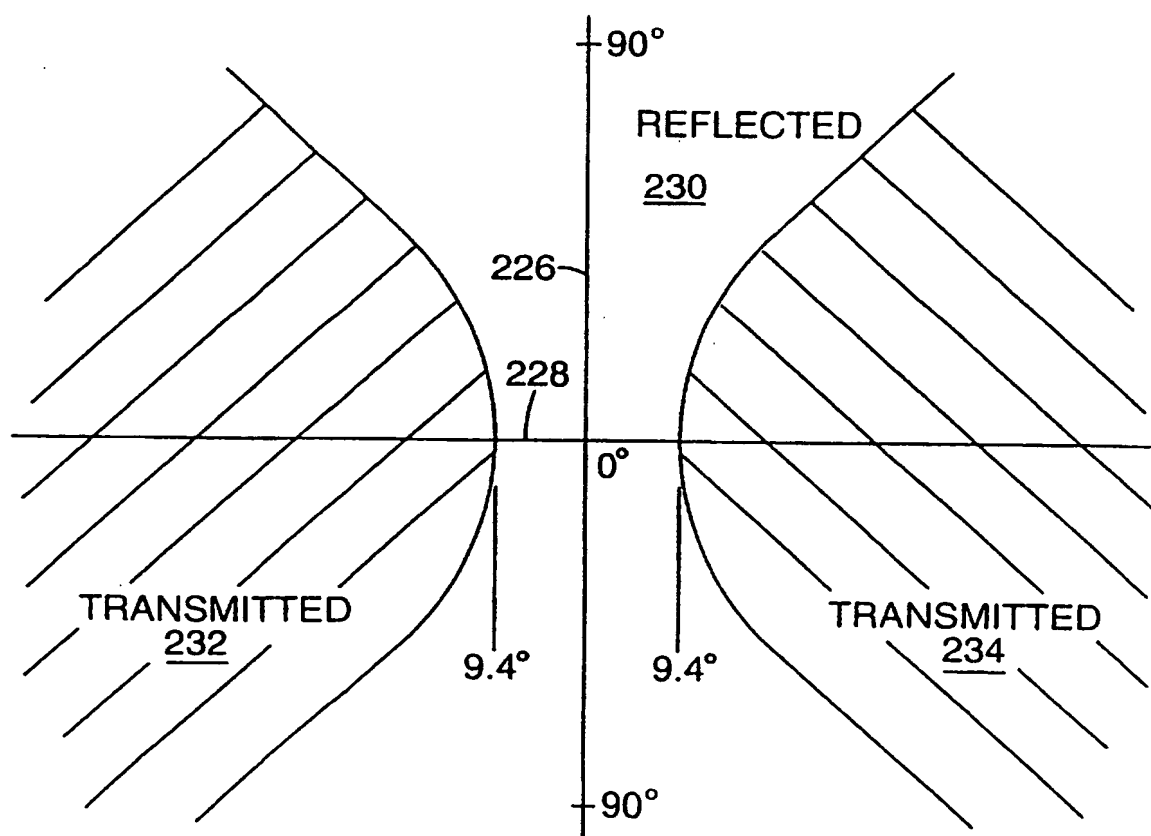
Fig. 11
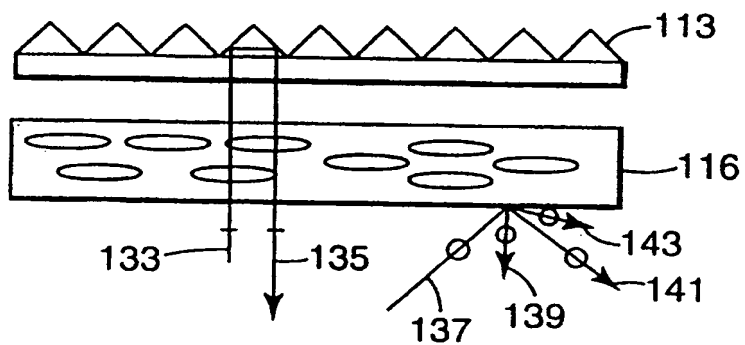
Fig. 12A

Fig. 12B

Fig. 13A

Fig. 13B

Fig. 14

Fig. 15
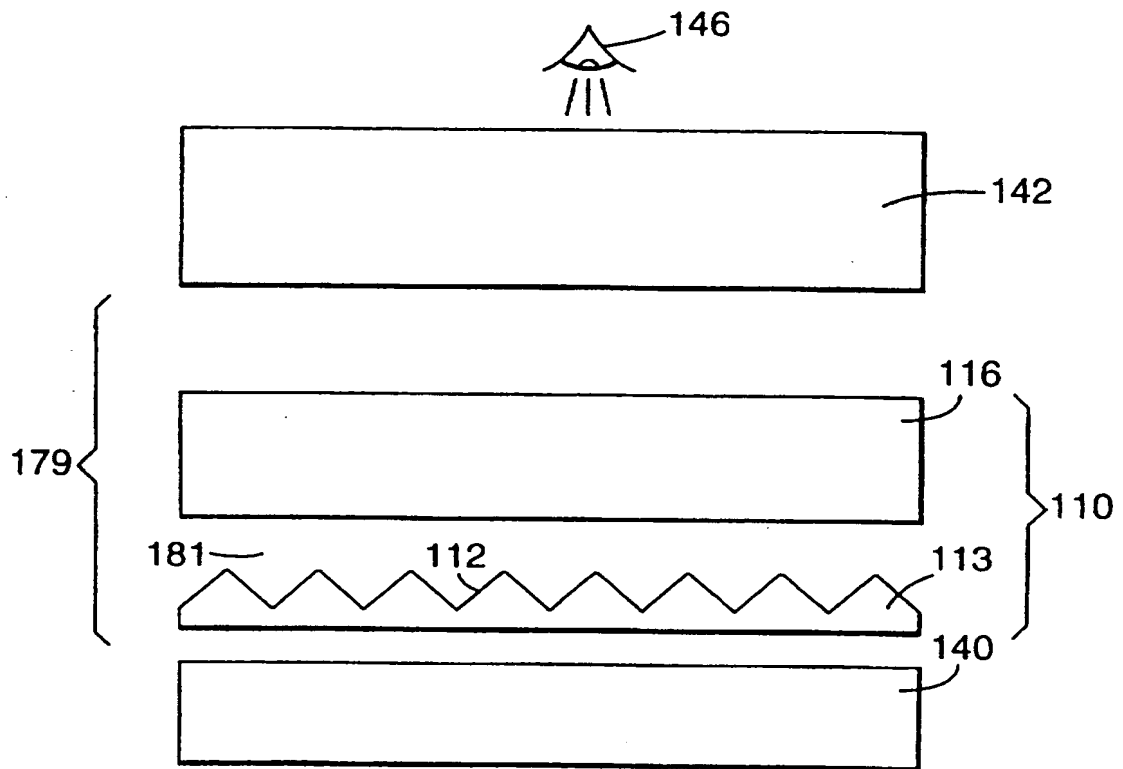
Fig. 16
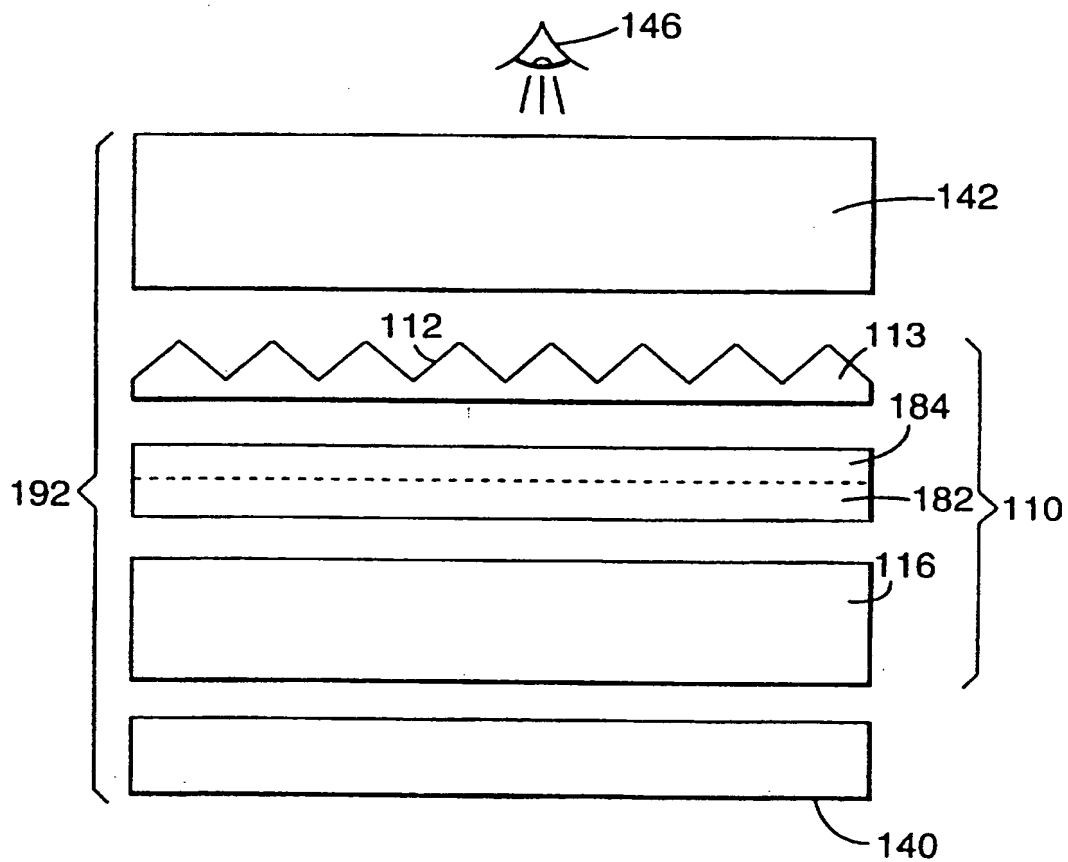
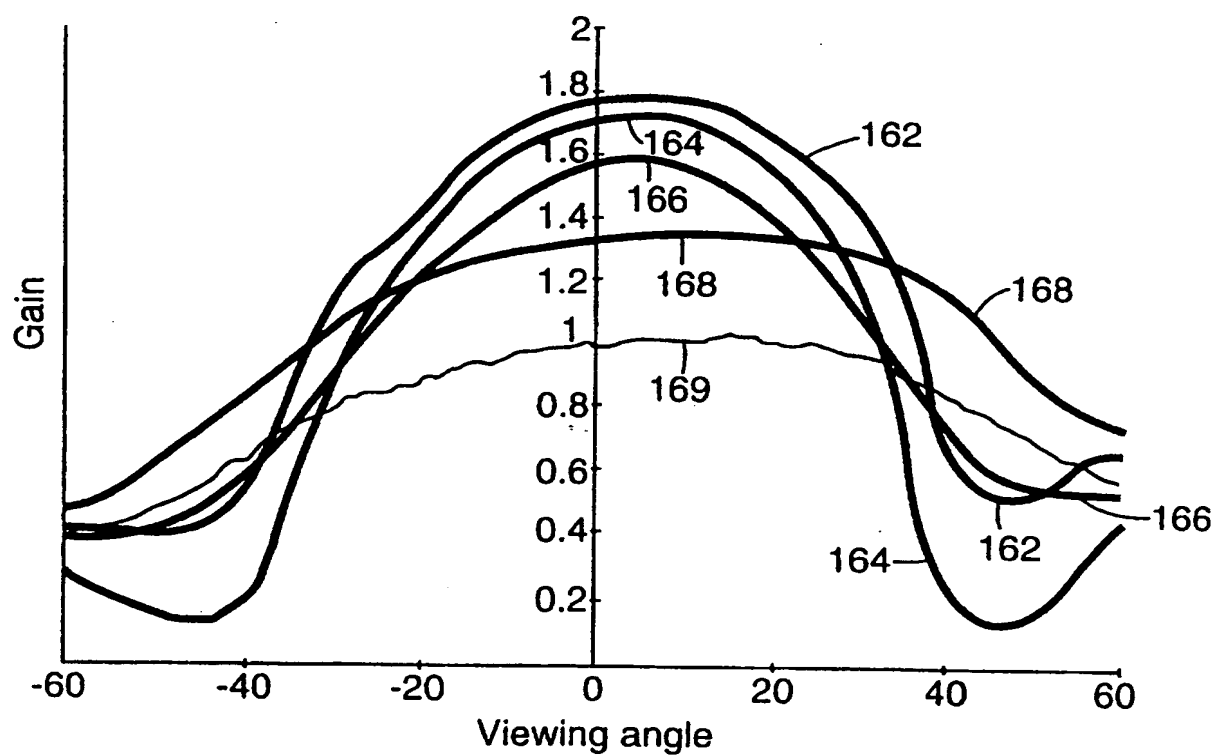**Fig. 17**

Fig. 18

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   G02B5/30   G02F1/1335

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   G02B   G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 95 17692 A (MINNESOTA MINING & MFG) 29 June 1995 cited in the application see the whole document ---	1-77
A	EP 0 597 261 A (ASAHI GLASS CO LTD) 18 May 1994 see the whole document ---	1-77
A	WO 94 29765 A (MINNESOTA MINING & MFG) 22 December 1994 see page 4, line 10 - page 9, line 16; figures 1-4 ---	1,4-20, 42-63, 76,77
A	EP 0 684 423 A (CANON KK) 29 November 1995 see page 6, line 19 - page 10, line 42; figures 4-16 ---	1-77

-/--

[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

* Special categories of cited documents :

'A' document defining the general state of the art which is not considered to be of particular relevance
'E' earlier document but published on or after the international filing date
'L' document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
'O' document referring to an oral disclosure, use, exhibition or other means
'P' document published prior to the international filing date but later than the priority date claimed

'T' later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
'X' document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
'Y' document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
'&' document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 June 1997	02.07.97

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl, Fax (+ 31-70) 340-3016	THEOPISTOU, P

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 394 255 A (YOKOTA TOMOHIRO ET AL) 28 February 1995 cited in the application see column 6, line 8 - column 11, line 22 see column 15, line 13 - column 19, line 68; figures 11-14,17-27	1,5-9, 11-18, 22-34, 42-44, 76,77

A	US 2 604 817 A (O. E. SCHUPP) 29 July 1952 see column 3, line 51 - column 7, line 44; figures I,II	1,2, 42-44, 76,77

1

INTERNATIONAL SEARCH REPORT

information on patent family members

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9517692 A	29-06-95	AU 1443595 A CA 2178325 A CN 1142869 A EP 0736188 A	10-07-95 29-06-95 12-02-97 09-10-96
EP 0597261 A	18-05-94	JP 6337413 A JP 7049496 A US 5587816 A	06-12-94 21-02-95 24-12-96
WO 9429765 A	22-12-94	NONE	
EP 0684423 A	29-11-95	AU 670403 B AU 2030795 A CA 2150340 A CN 1144913 A JP 8297282 A	11-07-96 04-01-96 28-11-95 12-03-97 12-11-96
US 5394255 A	28-02-95	JP 5203950 A JP 5313004 A JP 6043310 A CA 2088113 A EP 0556606 A US 5552907 A	13-08-93 26-11-93 18-02-94 28-07-93 25-08-93 03-09-96
US 2604817 A	29-07-52	NONE	